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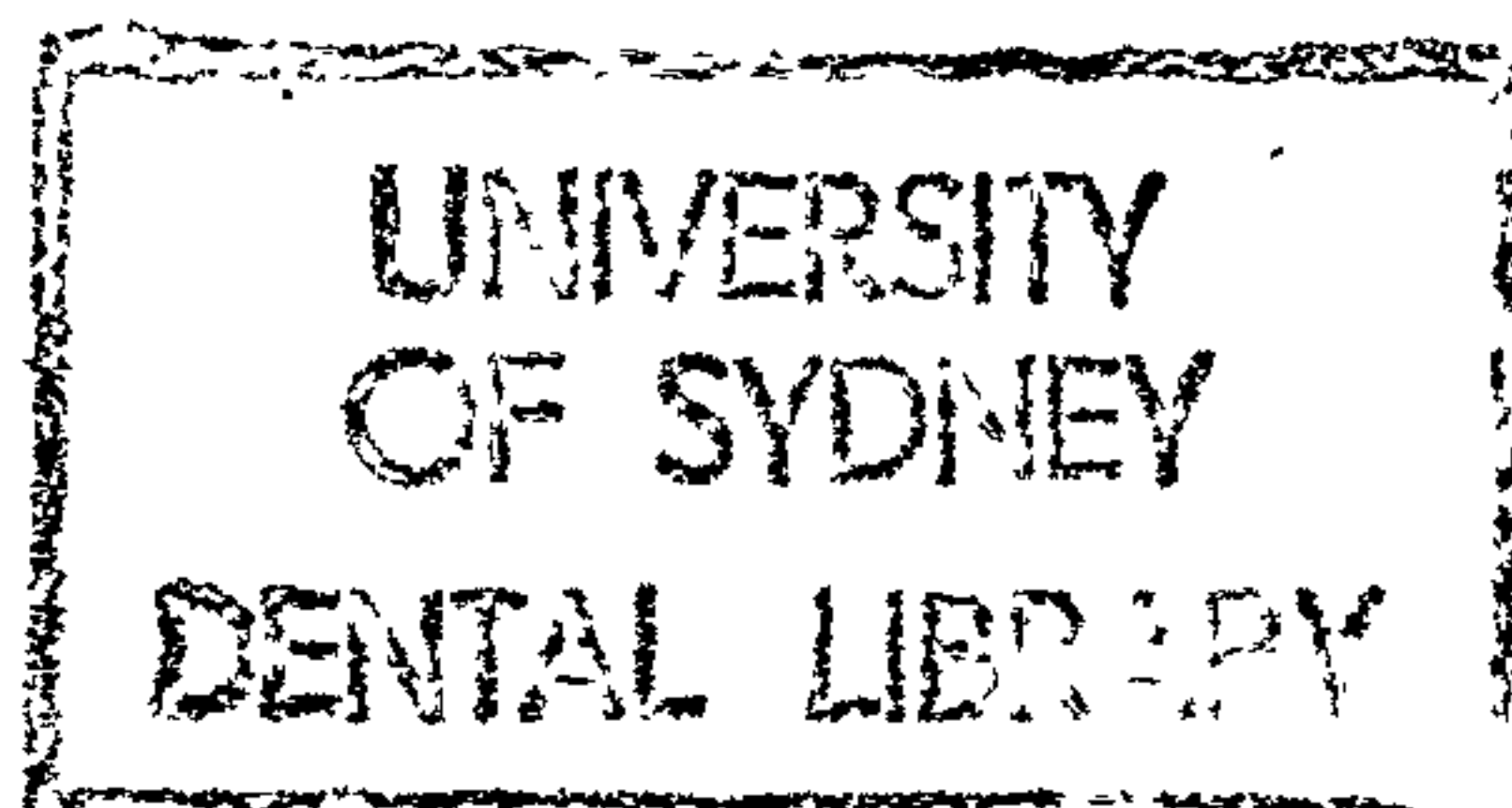
RADIOLOGICAL HAZARDS IN DENTISTRY

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A Thesis submitted in partial requirement
for the

DIPLOMA IN PUBLIC HEALTH DENTISTRY

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T A B L E . O F C O N T E N T S

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1. INTRODUCTION

Some human exposure to ionizing radiation is inescapable in the form of cosmic radiation from outer space, and radiation emitted into our environment, by naturally occurring terrestrial radionuclides.

Ever since the discovery of X-rays and radioactivity around the turn of the last century, there has been the question of under what conditions, for what ends, and to what extent, it is desirable to permit or to accept an increase in our exposure to ionizing radiation beyond normal levels of exposure from natural causes.⁴⁸

Yet for all the related research activity which has ensued there remains vast areas of concern in which too little is known or understood to define clearly the criteria needed for that assurance of radiological health, either on a population or in an individual basis. These circumstances demand a cautious approach in the development of the best subjective judgements that can be devised in the interests of human welfare.

History records that Wilhelm von Rontgen⁵⁹ first discovered the diagnostic value of X-ray radiation in the year 1895 and that within a matter of weeks this method of investigation was applied to the jaws and teeth. As it was customary then

to employ exposures in the region of twenty to thirty minutes, it would appear inevitable that the first recorded evidence of misuse of x-radiation appeared as early as 1896. With insufficient knowledge of these dangers and particularly with the use of tubes which were not designed or screened to protect them many of the early operators received excessive doses of radiation, and developed later hideous lesions involving their fingers and hands; many died as a consequence.¹⁸

It is of considerable concern to us to see that the patient irradiated, the dentist and other personnel who form the dental team in the surgery, are protected from the hazards associated with the necessary use of radiological techniques in the diagnosis of dental disease.

The question here is whether an individual who has been exposed to relatively small doses of radiation has a statistically significant, increased likelihood of developing one of the many effects known to be caused by radiation at relatively high doses. Among such effects are leukaemia, cancer and genetic damage.¹⁵

The aim of this paper is to carry out a review of the literature related to radiological health, particularly as applicable to dental practice and to attempt to provide a knowledge of the proper use of radiological techniques.

2. RADIATION. 38, 59, 132

Radiation is the propogation of energy in the form of waves; also, the energy so propogated. Radiation may be divided into two groups :

1. Corpuscular radiation which includes alpha and beta particles given off by radium and radioisotopes, and protons, positrons and neutrons resulting from the splitting of the atoms. These are solid particles having mass and, with the exception of neutrons have electrical charge.

2. Electro-magnetic radiations, which include roentgen rays, are pure energy without mass. All have certain fundamental common characteristics, namely -

1. They travel through space in a wave motion.

2. They travel at the same speed, the speed of light (186,000 miles/sec.).

3. As they travel through space they give off an electrical field at right angles to the path of propogation, and a magnetic field at right angles to the electric field.

4. They have measurable but different temperatures.

22

The fundamental difference between the several electromagnetic radiations is wave length; as wave lengths change the useful properties change.

ELECTROMAGNETIC SPECTRUM

In the diagram of the electromagnetic spectrum the wave lengths between 4,000A and 7,600A are called the visible portion because the human eye is sensitive to them.

(1 Angstrom unit A = 1×10^{-7} mm or about 1/250,000,000 in)

Red has the longest wave length while violet has the shortest.

Red has a warmer measurable temperature than violet.

The table 1 gives the relative positions in the electromagnetic spectrum occupied by the various types of rays. Of these a few are of particular interest :

Ultraviolet Rays

While there is no human sensory perception for ultraviolet, it can darken a photographic emulsion, as can visible light. In addition, it can penetrate living tissue for a depth of a few millimetres and cause biologic effects. Chief among these are :

1. photoerythema (sunburn)
2. photopigmentation (suntan)
3. cornification of the skin and possible skin cancer (as in farmers and fishermen)
4. photochemical formation of vitamin D
5. bactericidal action and cause certain salts to fluoresce.

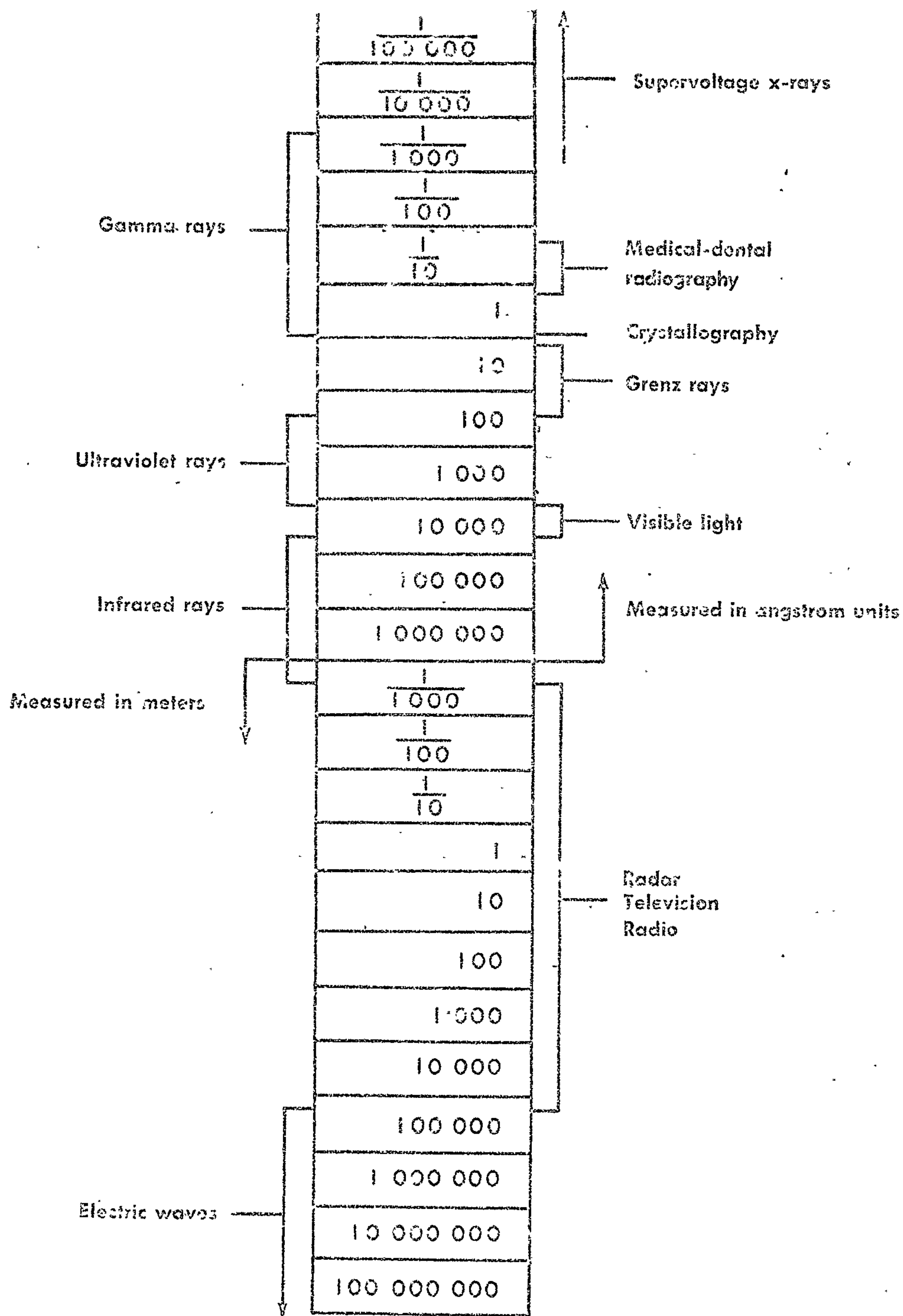


Table 1 ELECTROMAGNETIC SPECTRUM

Upper and lower limits not yet defined

Shorter waves measured in Angstrom units

Longer waves measured in meters or in secs. per cycle.

The chief properties can be summarised as follows :
biologic effect, photographic effect and fluorescent effects.

X-rays or roentgen rays

These are shorter than ultra violet rays. Rays with a wave length of 0.8 to 0.1A are used in dental radiography.

Roentgen rays exhibit the same properties as U.V. rays.

1. It has an even greater penetrating power and hence is capable of eliciting a more intense biologic effect. Used in medical therapy.

2. Causes salt to fluoresce used in medical fluoroscopic examination.

3. Ability to darken photographic emulsions which is the basis of medical and dental roentgenography.

Opposite the X-ray portion of spectrum is a band of wavelengths produced by natural radioactivity, the disintegration of radium. In the process of disintegration alpha, beta and gamma rays are emitted until a stable end product is reached. In clinical radium therapy, gamma rays are far more important than α or β , since the latter have minimal penetrating power.

At the top of the electromagnetic spectrum lie the radiations with the shortest wave lengths and the greatest energies - the cosmic rays. These are particles having mass, which originate in outer space. Cosmic rays continuously bombard the earth and its

inhabitants with small but measurable amounts of radiation, and have done so since the earth was formed.

X-rays similar to those produced by man also arise in outer space and arrive at earth much as do light, radio and cosmic rays. Mapping of space X-rays is the newest branch of astronomy.

3. RADIATION TERMINOLOGY

A large number of descriptive terms have been formulated in the area of radiation biology. In general these terms pertain to three areas.¹⁴

1. The source of radiation such as isotope and half life.
2. The target of radiation such as RAD and REM.
3. The problems of nuclear warfare such as blast and fall out.

The terms that are revelant in the field of dentistry are explained in the following discussion for use in understanding data presented pertaining to radiological problems.

3.1 Exposure

The unit of exposure is the roentgen, which is a measure of the radiation, based on its ability to produce ionization in air under standard conditions of temperature and pressure. The roentgen is not a direct measurement of the intensity of x-radiation, of the energy absorbed in air, or of the biological effect, although these may be calculated from the results of such measurements of ionization, if certain other pertinent factors are known.⁷⁷ Therefore, it does not directly indicate the area of exposure or the dose to the tissue beneath the body surface. For example, if an X-ray

generating machine gave an exposure of one roentgen per second in air at a specific distance from the X-ray source, all the points within a 10 inch by 10 inch irradiated field would receive one roentgen for a one second exposure. This same 100 square inch field could be exposed to one roentgen by use of one square inch of tissue for one second. In both instances, the exposure to the surface would be identical. The total exposure measured in the beam would show one roentgen per second in the first instance and 100 roentgens per 100 second in the second instance. Hence care must be used with the units when exposure is expressed in roentgens. It is therefore evident that a one roentgen exposure for each projection of a 16 film series does not result in a 16 roentgen exposure to any single area of the patient. The official definition of the roentgen adopted by the National Council on Radiation Protection and Measurement is as follows :-⁷⁸

"The roentgen shall be the quantity of x - or gamma - radiation such that the associated corpuscular emission per 0.001293 gram of air produces, in air, ions carrying less of quantity of electricity of either sign."

3.2 Dose.

The unit of absorbed dose is the RAD - radiation absorbed dose, which is a measure of the energy absorbed by matter per unit mass of radiated material. The RAD is defined

as 100 ergs of energy absorbed per gram of material. When dealing with the biological effects of radiation, we are interested in the amount of energy that is absorbed by the biological material, since presumably there is no biological effect without absorption of energy.³

The roentgen, then, is unit of measurement which describes the radiation field. A RAD describes the amount of energy absorbed. Ionizing radiation can have a biological effect only when it imparts energy to matter. Therefore a tissue exposed to a field of radiation measured in roentgens - exposure - will absorb an amount measured in RADS - dose. It is evident that biological effects are correlated more closely with "dose" than with "exposure". Because of a lack of understanding of these concepts in the past, confusion and misconceptions have been prominent in the discussion of exposures or doses on a per film basis in dental radiography.

This is well illustrated by Alcox³ in reference to a study by the U.S. Public Health Service of X-ray Exposure in 1964. They reported an average mean exposure per dental film of 1138 mr. The same study reported a mean exposure of 45 mr for a radiographic chest examination and 504 mr for a photofluoroscopic chest examination. At first glance the figure 1138 mr appears to be significantly large in comparison with the 45 mr for a radiographic chest examination. However, a comparison based only upon an average milliroentgen

exposure is deceptive and misleading. Since the reported exposure per film does not take into account the size of the field as previously discussed and the volume of tissue irradiated, or the specific operating characteristics of the machine and specific film speeds and techniques used.

Both Roentgen and RAD^3 are expressions of physical phenomena, neither being an indication of biological effects produced in the tissues by the several types of radiations. The unit used to express the comparative biological effects on tissue irradiated by different forms of energy is the RBE, relative biological effectiveness. X-rays in the medical and dental diagnostic range have been assigned arbitrarily an RBE of 1 unit: gamma rays are also 1 RBE, but for neutrons and positrons up to 10 million volts have a relative biological effectiveness of 10.

3.3 Integral Absorbed Dose

This quantity is defined as the total amount of absorbed energy in a given volume of interest.¹²⁴ The unit of measurement is the gram - rad - 1 gram - rad = 100 ergs. The most practical clinical unit devised to combine both physical and biological aspects is the REM - Roentgen Equivalent Man; This is the unit of the RBE dose, and is determined by multiplying the absorbed dose - rad - by the RBE of the radiation used. Since the X-rays used in dentistry have an RBE of one, 1 rem = 1 rad.

Biological effects from radiation are not usually thought of as the result of the absorbed dose at a certain point, such as the surface of the skin, but are believed to be determined by the total amount of absorbed energy imparted to the region of interest. The integral absorbed dose is integral with respect to the mass of the absorbed dose throughout the irradiated volume.⁷⁸ This is one of the most useful concepts in dosimetry when comparing radiation contributions from different radiographic procedures.¹²⁰

4. RADIOBIOLOGY.

Radiation has the property of ionizing matter through which it passes, either directly or indirectly. Its other important general characteristic is that it will pass through material substances. These two properties result in certain biological, physical and chemical changes in the material through which radiation passes.

The biological effects of radiation¹⁵ on living organisms are still not well understood, but experimental observations have led to certain accepted beliefs such as :

1. All living cells are subject to change (usually undesirable) by being exposed to radiation.
2. The amount of change is related to the amount of radiation exposure and is usually proportional, although it is not known to what degree this relationship extends in very low doses which approach background levels. For genetic material, there is a general and growing belief that there is no threshold of dose below which genetic change will not result.
3. Living cells have a relatively higher biological response to highly ionizing particles (neutrons, alpha particles, protons, etc.) having higher rates of linear energy transfer (LET) than to the more common X-rays gamma radiation and beta particles.
4. Some biological effects of radiation are subject to recovery; others are not. Recovery is probably attained by the

elimination of damaged cells or products of radiation at a higher rate than the rate at which the damage is sustained or increased, by the reproduction of damaged cells.

5. The radiosensitivity of the various types of tissue vary widely.⁷²

The radiosensitive group in decreasing order of radiosensitivity

1. blood forming tissues
2. reproductive cells
3. lymphatic tissue
4. young bone cells
5. skin

The radioresistant group in decreasing order of resistance.

1. most glandular tissue
2. muscle tissue
3. nerve tissue
4. mature bone tissue

All ionization is assumed to be hazardous and the underlying process by which radiation produces cellular changes is one of ionization.¹⁴ Ionizing radiation affects tissue through a process whereby electrically stable atoms and molecules become electrically unbalanced. This process occurs when a quantum of ionizing radiation strikes a subatomic particle in one of the molecules of the cell. These subatomic particles are variously designated as protons, neutrons, electrons, and

so forth. The subatomic particle may be displaced by the energy of this quantum, and if the particle carries an electric charge as do electrons and protons, a change in electric charge occurs and the molecule assumes a different electric charge. It now becomes electrically unstable or reactive. The molecule is now described as ionized, and the basic principle may be summarized by saying that ionizing radiation creates ionized molecules. If an electron is displaced the molecule assumes a net positive charge. In living tissue there is a strong tendency for atoms and molecules to seek electric stability and now the positively charged molecule seeks out a negative charge with which to combine. As a result of such combinations, a new chemical may be formed within the cell, and the function of the cell in which this reaction occurs may be altered.

4.1 Radiation Theories.¹⁴

There are two main principle ideas in all theories advanced to explain the effect of ionizing radiation on living tissue.

1. Direct action. In this instance the effects of radiation are produced by damage to or destruction of a specific vital molecule in the cell.
2. Indirect action. Radiation does not directly damage vital cell molecules but may result in the formation of altered chemicals which are toxic to its normal function, within the cell. These altered chemicals indirectly produce cell damage and death.

Because ionization is a random process, the molecules that run

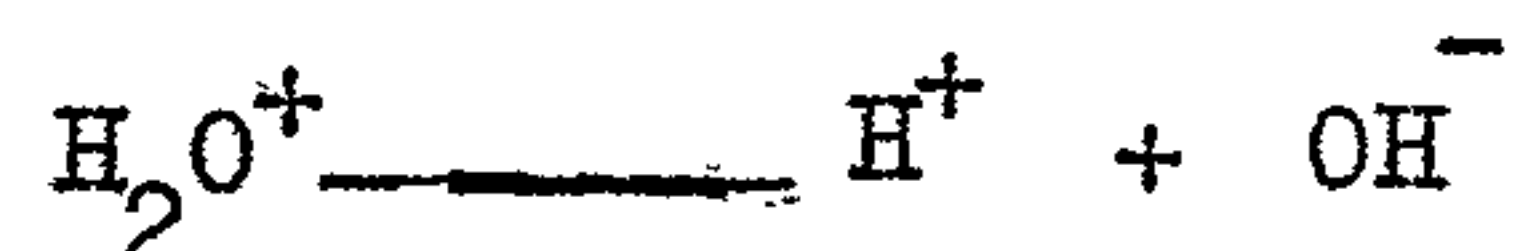
the greatest risk of radiation are those present in the largest numbers. In most cells this is water, which consists of atoms of hydrogen and oxygen. The electron loss produced by radiation results in unpaired electrons in the orbital shells of these two atoms. These resultant atoms are called free radicles and are very reactive with other atoms in the cell. Thus energy transferred from radiation to water can produce a critical change and even a loss of function. Not every atomic interaction with ionizing radiation results in a molecular ionization. Excitation of the molecules accounts for a significant percentage of energy dissipated by ionizing radiations in tissue. Excitation in the process of causing electrons in the outermost shell of an atom to move even further away from the nucleus. The result is a change in the energy forces that bind these electrons, and this altered electron position called excitation may, in turn, alter the chemical bonding forces of atoms within molecules.

CHEMICAL TRANSFORMATIONS PRODUCED BY IONIZING RADIATION

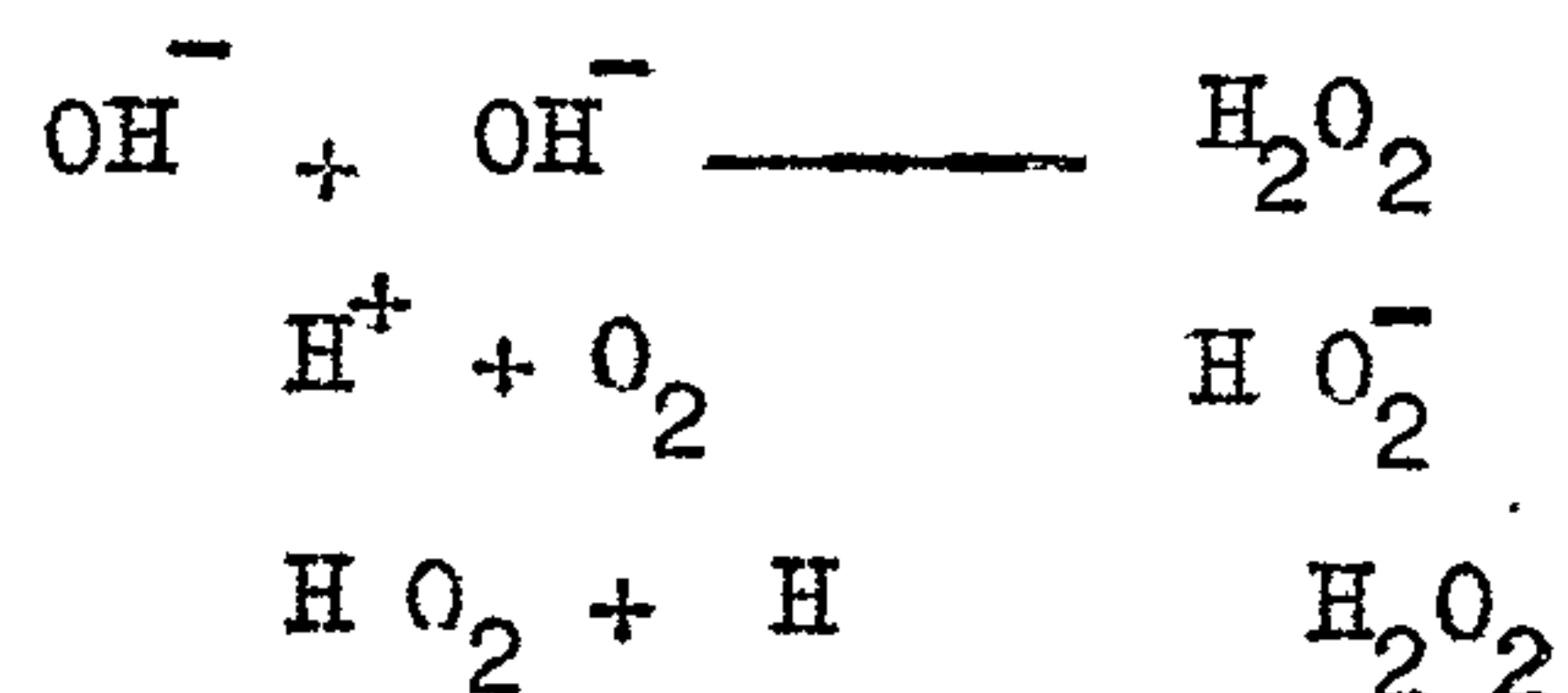
1. Ionization



2. Activation



3. Chemical changes



4.2 The Chromosomes. 119, 13

Radiation is known to cause breakage of the chromosomes presumably in a random manner at or near the point of energy absorption.

Following such a break a number of things may follow :

1. reunion of the broken ends
2. union with the broken ends of adjacent chromosomes
3. remain unjoined, leading to the loss of genetic information at anaphase.

Other induced changes include surface stickiness and inactivation of the centrosomes. The full significance of these effects of radiation induced changes, in the chromosomes is as yet little understood. However, the radiosensitivity of individual cells is variable, generally being high at a following chromosome replication.

4.3 Damage and Repair to Nucleic Acids.

As the reproductivity of a cell is one of its first activities to be effected by irradiation, an obvious target for sublethal damage is the deoxyribonucleic acid (DNA) of the nucleus.

Irradiation has been found to produce cross linking either within the DNA strand or between paired strands. However, the nature of such linkage is unknown.

Damaged portions of the DNA strand appear to be excised with the aid of enzymes and the exposed area subject to repair synthesis or unscheduled synthesis.

The capacity for repair to DNA exists throughout the cell

cycle and a significant increase in the molecular weight of DNA, indicating rejoining of broken strands following irradiation has been found to occur within 20 minutes of irradiation.

Rejoining of broken strands may also be accomplished by filling in of the gaps with new nucleotide sequences. Although it is obvious that the change of the sequence of nucleotide bases may or may not have an effect on the cell chemistry and that these changes occur in a random manner, the importance of this type of repair is unknown.

Cell death will occur for many different reasons as it is unlikely that more than a small percentage of cells should be injured in identical ways by a direct hit.

4.4 Mitosis.^{119 13}

The effects of non lethal irradiation doses on cellular mitotic division is characteristic and includes

1. An initial decline in numbers of dividing cells.
2. A following period in which the number of dividing cells remain reduced, the length of this period being dose dependent.
3. An increase of the mitotic activity to a level exceeding that of the pre-irradiated tissue
4. A gradual setting back to a level approximately equal to that of the pre-irradiated tissue.

4.5 Cellular Morphology.^{119 13}

Changes occur within cells similar to those seen for most

non-specific toxic stimulants. These changes include :-

1. Nuclear swelling, pyknosis and vacuolation
2. Nuclear budding and lobulation
3. Karyolysis
4. Chromatin clumping
5. Extrusion of chromatin
6. Loss of mitochondria

These changes can often be detected within minutes of the irradiation.

4.6 Cell Survival Curves.¹¹⁹ 13

The relationship between cell survival and radiation dose is often demonstrated by graph plotting the surviving fraction of cells, i.e., those that have not lost their capacity to proliferate on a logarithmic scale, against dose on a linear scale. - Figure 1.

When plotted for low energy transfer (LET) radiation with the exception of neutrons which is a form of high energy transfer, (HET) radiation, mammalian cells show a characteristic initial region of low sensitivity.

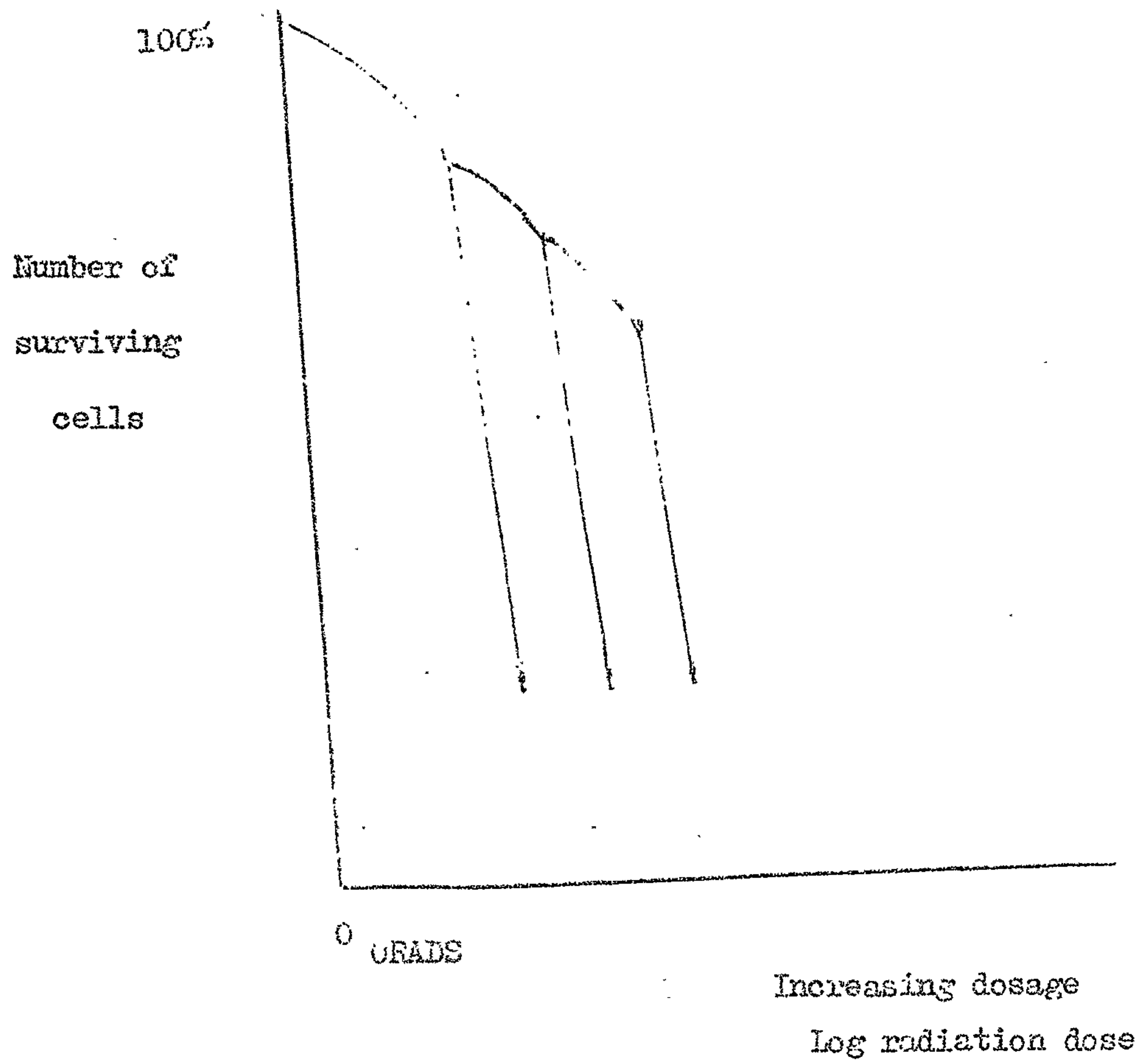


Fig. 1 CELL SURVIVAL

This initial low sensitivity produces a shoulder on the graph Figure 1. The shoulder suggests that diploid and polydiploid cells can receive some degree of non lethal injury before being subject to death by additional energy transfer. Fractional dosages produce a series of shoulders and this indicates that cells are able to repair some of their radiation injuries between doses.

Such cell survival curves have been found to predict quite accurately, the response of haemopiretic death and intestinal death in mice. These curves were derived from studies of tissue cultures of the respective stem cells. However, they do not take into account such factors as variation of oxygen tension in a given tissue mass and so can only indicate cell sensitivity and are therefore not necessarily accurate for tissues or tumors.

The extent of the shoulder, ie., the size of the non lethal dose, varies between the different types of mammalian cells and there are many other factors which affect this property (D_q) in a given colony. It has been found that for a given cell line the value of D_q can range between almost zero for cells in mitosis and 700 RADS for those in late synthesis phase.

Consequently, the ability of a cell to divide is usually lost before its ability to survive. This factor of sublethal damage, however, may also produce characteristically poor response of irradiated tissue to injury. Much of this response can be attributed to poor blood supply, but something more than ischaemia is necessary to explain the onset and the characteristics of many of the "so called" delayed effects.

5. BIOLOGICAL EFFECTS.

Even though both the effects of radiation on the individual and the effect to his offspring may well have a common origin in the genetic material, it is nevertheless quite convenient to consider these two categories separately.

5.1 Genetic Effects.

Offspring of man and animals arise from a single cell formed by the fusion of two germ cells, the ovum of the female and the sperm cell of the male. The germ cells (gametes) contain genes in the chromosomes of their nuclei which determine the characteristics of the offspring. The genes are composed¹⁴ of deoxyribonucleic acid (DNA). The DNA molecule has subunits called nucleotides where the genetic message is stored. The particular genetic message that is stored in these molecules is coded, in the kinds of nucleotides used and the sequence in which they are arranged. Any alteration of their structure or replacement of a nucleotide will be sufficient to alter the genetic message and thereby permanently alter the function of the cell. Such nucleotide changes are called mutations.

5.2 Mutations - Natural.¹⁴

Mutation is a naturally occurring phenomenon. Since every known species of plant or animal utilizes the DNA molecules for its genetic messages it is therefore susceptible to mutation. All mutations,

with rare exceptions, are considered to be deleterious to the organism that has them, hence any increased frequency of mutation is undesirable. However, naturally occurring mutations have considered a process of natural selectivity whereby the undesirable characteristics of a species tend to die out and the desirable characteristics are increased in number.

5.3. Mutations - Radiation Induced.

Mutation frequency is affected quite dramatically¹⁴ by chemicals, viruses and radiation. The mutations induced by radiation could be categorized as undesirable as it interferes with the process of natural selectivity.

The most relevant information for determining the possible genetic damage induced by radiation in man comes from the extensive experimentation with the effects of radiation on animals.

In somatic cells an elaborate enzyme system exists, which can remove undesired radiation - altered nucleotides and restore the proper nucleotide sequence and cellular function. This system does not operate in the germ cells,¹⁴ which have a haploid chromosome constitution, and such repairs do not take place. Thereby radiation-induced alterations in the DNA molecule are essentially permanent changes when they occur in the sperm or egg. Offspring carrying these deleterious mutations may be the final result.

5.4 Drosophila - The Fruit Fly.

Herskowitz and BauMiller⁵¹ observed the effect of radiation induced mutations in *Drosophila*.

Heterozygous mutations produced by 3000 r, delayed pupation in about 9 percent of larvae of *Drosophila melanogaster* under nutritional stress and killed approximately 6 percent. The effects are less, though appreciable, when there is excess nutrient. Following irradiation of the females there was a significant detriment in both son and daughter larvae from eggs laid during the first 6 days after mating. For eggs laid on days 7 through 13 were not significantly different from those for the unirradiated controls and are significantly lower than those for comparable eggs laid on days 2 through 5. The 9th day pupation rates for eggs laid on days 7 through 13, though they do not differ from those of the controls in the case of daughters, show some effect of irradiation in the case of sons, and the effects on both sons and daughters were significantly less than those for comparable eggs laid on days 2 through 5.

They observed that these results correlated with those from other experiments, where similar females were irradiated. In these recessive lethal mutation rates were significantly reduced among eggs laid more than 6 days after irradiation as compared with eggs laid earlier.

Their experiment while exhibiting the effects of radiation have observed that the mutation rates were reduced by the passage of time and influenced by nutrition. This is contrary to the view that

genetic material in the germ cells do not have the power of repair due to the non-existence of an elaborate enzyme system like that found in the somatic cells.¹⁴ However, they have accounted for this apparent discrepancy, by stating that the eggs were in a different stage of development.

5.5 Mice.

A review of an article by Russel⁸⁹ on radiation genetics in the mouse supplies important information relative to radiation effects on germ cells.

One of the first questions to be considered was whether offspring conceived say 18 months after irradiation of the male, are likely to bear a mutation as those conceived 3 months after irradiation.

These results indicate that there is no change in the frequency with the passage of time even up to the end of the reproductive life (2 years of age in the mouse).

However, mature spermatogonia and oocytes are somewhat more sensitive to radiation than young developing spermatozoa. It seems then that mutagenetic events in the male or female persist and may be carried on into the progeny.

One of the basic tenets of radiation genetics has been that the mutagenic effect of ionizing radiation is a direct function of the total dose and independent of dose rate. This conclusion

originally was based upon experiments in which the spermatozoa of the fruit fly *Drosophila*, was irradiated.⁵¹ Russell and co-workers have confirmed with mice that the mutagenic effect of ionizing radiation on the spermatozoa is a direct function of the total dose and independent of the dose rate.⁸⁹

Russell reasoned that it was the spermatogonia and oocytes, and not the spermatozoa and ova, which were present in the mammal from birth, and that the experience of these cells with radiation, rather than that of the spermatozoa and ova, was of the greatest genetic importance. Russell's research indicates that less genetic damage is done to the spermatogonia and the oocytes at lower rates of exposure than at higher rates. For chronic dose rates (10 to 9m₂ per week), the genetic effect on the male mouse is about one fourth and on the female mouse about one seventh of the effect caused by acute doses of 80 to 90 per minute. Recently it has been proved that the lower mutagenic effectiveness of chronic radiation over acute radiation holds true also in the *Drosophila*.⁸² From the results of Russell's investigation, it appears that the genetic hazards at least, under some radiation conditions may not be as great as those estimated from the mutation rates obtained with acute irradiation.

The discovery of the reduced mutagenicity of chronic irradiation therefore has introduced into the field of radiology a factor of safety which previously was not known to exist.

5.6 Man.

The very unfortunate incident of the atomic bombing of Hiroshima and Nagasaki has provided the world with a wealth of information on the genetic effects of radiation.

A large scale study was conducted as a cooperative venture between the National Research Council (NRC) representing the United States and the Japanese National Institute of Health.⁶⁵

The study from 1948 to 1953 consisted of 71,280 pregnancies of which 93 percent of all went to term in that interval. About 40 percent of the children were re-examined at the clinics when they were 8 to 10 months old. The results were distributed according to five levels of radiation exposure for each parent.

1. No influence of radiation was demonstrable which statistical tests have shown was likely to detect a 2-fold increase in rates of malformation or a 1.8 increase in rates of still births and deaths of newborn.
2. No effect on birthweight or on anthropometric values at 8 to 10 months attributable to radiation exposure.
3. In a study of 120,000 births, such shifts in sexratios were found to occur in the first 10 years following detonation of the atomic bombs but not thereafter.
4. No effect has been found in the mortality of children conceived after exposure of their parents.

5. Though laboratory tests leave no doubt that irradiation is mutagenic, the effect could not be demonstrated in the F₁ generation.

It is of considerable importance to the dentist to elicit evidence pertaining to whether there is a threshold dose of radiation below which no mutagenic events occur. A complete answer is still not available and since the lowest levels produce so few mutant genes that a tremendous number of offspring must be observed and counted in order to obtain a true measure of mutation frequency. The genetic effects of low dosage ionizing radiation on man are largely theoretical since little has been proved regarding them. This lack of proof stems from the great difficulties associated with obtaining quantitative evidence.

The upper limit of the rate of chronic irradiation reported by Russel⁸⁹ in his experiment on MICE was 90r per week or 0.15 mr per second. It is a matter of record that, under optimal conditions, the male gonads are irradiated at the rate of 0.3 mr to 0.34 mr per second when 60 to 65 Kilovoltage peak (KVP) are used in making dental X-ray examinations¹⁰² and 0.31 mr per second when 90 KVP are used. The dental irradiation of the female gonads has been reported to be at the rate of 0.01 to 0.06 mr per second when oral examinations are made with 60 to 65 KVP¹⁰⁵.

Filtration, collimation, voltage, current, focal skin

distance, angulation and length of torso are the physical factors which control the rate of exposure of the gonads. From these data regarding the dose rates it appears that the rates at which the gonads are irradiated during dental X-Ray examinations lie in the approximate range which Russel found to be less hazardous than was thought previously.

The total amount of radiation reaching the gonads during the complete periapical examination of the mouth with fourteen exposures is very small between 0.00043 R and 0.07 R.¹⁰⁰ It is well to remember that only the radiation reaching the gonads can be considered harmful from a genetic point of view, and then only in persons who are under or within the child bearing age.

Since the gonads do not lie within the path of the primary roentgen-ray beam, during a dental roentgenographic survey, the only exposure of the region must come from¹⁰²

1. Scattered radiation from the head of the patient through his body.
2. Scattered radiation through the air.
3. Radiation leaking from the head of the X-Ray machine.

To test for exposure of the gonads from leakage radiation, a thick lead diaphragm with no aperture was placed on the portal through which the primary beam emerges. This device prevented

exposure of the head of the patient. The usual times of exposure were used and the dose to the gonads was measured. No measurable amount of leakage radiation was detected at the gonads, with the brief periods of exposure that are used with dental patients.¹⁰²

To measure the amount of radiation scatter through the trunk of the patient, that would reach the gonads required that a sheet of leaded rubber be placed across the lap of the patient to exclude all exposure to scattering in the air. No radiation was found to scatter through the body of the patient.¹⁰² This observation is reasonable because more than 24 inches of tissue separate the gonads from the occlusal plane of the mouth, presents a very formidable barrier to the passage of any roentgen rays generated with low voltage.

Hence it follows that the radiation measured at the gonads is due to the scattered radiation from the head of the patient transmitted through air.¹⁰² The average gonadal doses listed in the Table 2 were not the doses absorbed by the gonadal tissue at the centre of the testicles, but only air doses. It was assumed that the average thickness of the skin of a testicle was $1\frac{1}{2}$ inches. An approximate factor 50 percent was determined experimentally for converting the air dose to the dose absorbed by gonadal tissue. The factor is the depth dose (expressed as a percentage of the air dose) that was measured $\frac{3}{4}$ inch below the surface of a large tub of water the surface of which was 26 inches from the focal spot of

Table / Comparison of exposure of gonadal region from complete and roentgenographic examination made 65 kvp and 90 kvp

Region	Vertical angulation	Time of exposure with 65 kvp seconds	Average of gonadal air dose with 65 kvp	Time of exposure with 90 kvp seconds	Average of gonadal air dose with 90 kvp	Reduction in gonadal air dose with 90 kvp %
Max. central incisors	+45	2.25	0.366mr	0.81	0.326mr	10.9
Max. cuspid	+45	2.00	0.334	0.72	0.295	11.7
Max. bicuspid	+35	2.00	0.338	0.72	0.296	12.4
Max. molars	+30	2.50	0.380	0.90	0.338	11.1
Man. Central incisors	-15	1.75	0.265	0.63	0.222	16.2
Man. cuspid	-20	1.75	0.243	0.63	0.215	11.5
Man. bicuspid	-10	1.75	0.268	0.63	0.231	13.8
Man. molars	0	2.00	0.264	0.72	0.237	10.2
Totals		28.00	4.285mr	10.08	3.772mr	12.00

the X-ray tube. A distance of 26 inches was chosen for this test because the distance between the gonads and the occlusal plane for the average subject was about 26 inches.

When this conversion factor is applied the effective dose at the centre of the testicle becomes 2.14 mr and 1.88 mr for complete oral roentgenographic examinations (14 films), made with 65 kilovolt peak and 90 kilovolt peak respectively.

Next Richards¹⁰² studied the effect of the length of the patient's torso on gonadal dose. In addition to measuring the contribution of each dental exposure to the gonadal dose, measurements were made of the distance from the seat of the dental chair to the occlusal plane of the seated patient. These latter measurements provided an approximation of the distance that the secondary or scattered radiation from the face travelled to reach the gonads. Figure 2 shows that the rate of exposure of the gonads falls rapidly with increasing length of the torso. Part of the effect of the higher rate of gonadal exposure of the child is cancelled by the shorter time of exposure that is indicated by the child's thinner structures, but the two factors do not cancel each other. The effect of these two factors on the gonadal exposure of the child are illustrated in Table 2 in which the values for the rates of gonadal dose taken from curve D in Figure 2 are used.

This example indicates that although a three year old child has a relative rate for gonadal dose $2\frac{3}{4}$ times that of an

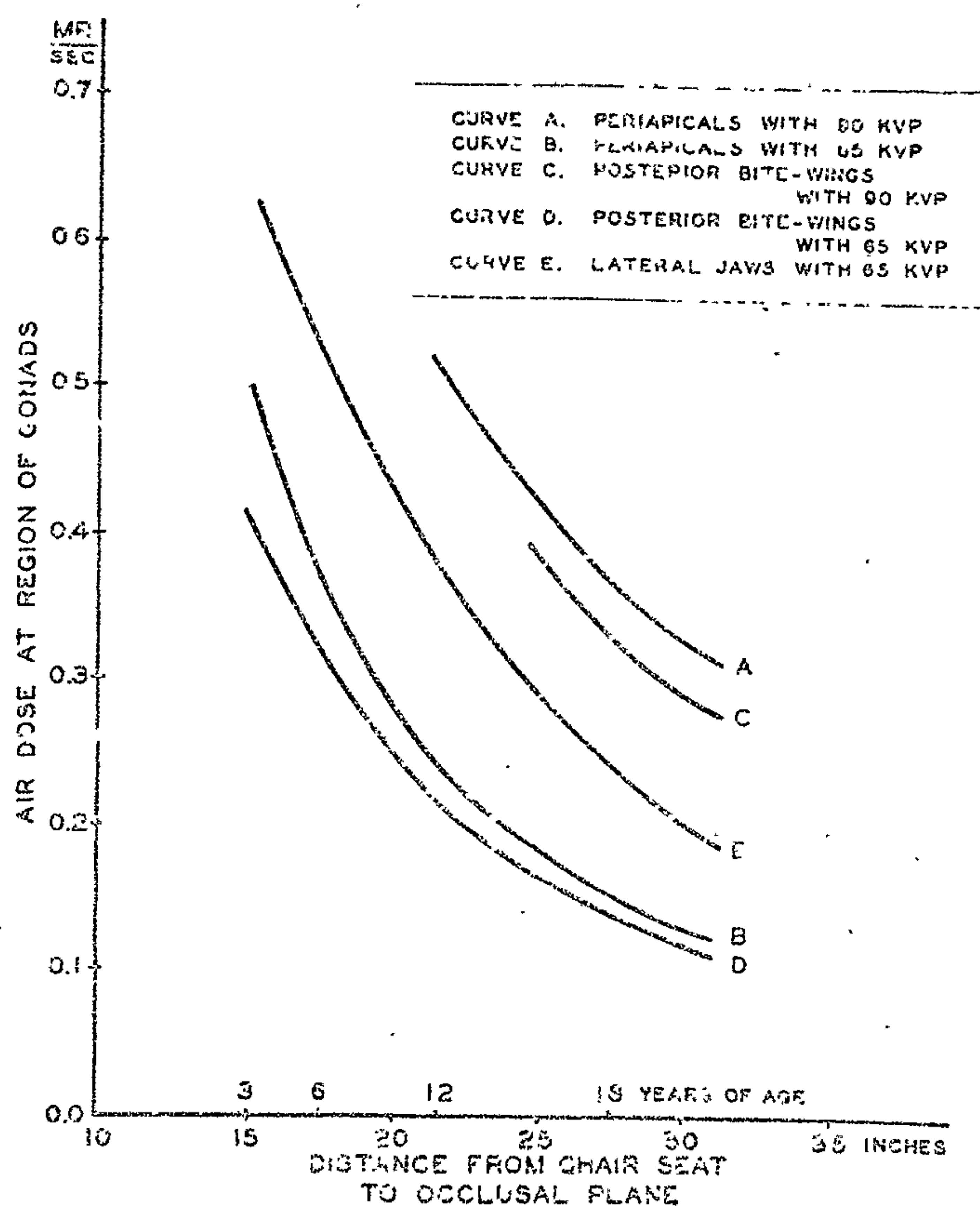


Fig. 2 Gonadal doses (measured in air) for various techniques at functions of length of patient's torso.

Technical factors :- 10 Mg

Target skin distance 7.0 m

Diameter of roentgen-ray beam

at a distance of 7 m - 2.5 in.

Table 2. Effect of higher rate of gonadal exposure
of child and shorter time of exposure.

Rates of gonadal dose taken from Curve D in

Figure

Age	Gonadal air dose rate	Relative gonadal air dose rate	Relative times of exposure	Relative gonadal dose
18 years	0.14mr/sec	1.00	1.00	1.00
12 years	0.22mr/sec	1.57	0.90	1.41
6 years	0.31mr/sec	2.21	0.75	1.66
3 years	0.38mr/sec	2.72	0.65	1.77

adult, his relative gonadal dose is only $1\frac{3}{4}$ times that of an adult because of this difference in structure.

Table 4 gives further changes in technique which show that the dose could be further reduced.

A number of studies have reported on the amount of gonadal radiation received by the dental patients.

Richards reports that a complete oral roentgenographic examination consisting of 14 films, according to the technique used by him, exposes the gonads of the adult man to an absorbed dose of 2.14 mr.

In 1955 Stanford and Vance¹⁰⁵ reported a 0.34 mr gonadal dose to males and 0.06 mr to females using a 60 KUP, 10 MA, 8 inch target film distance and 1 second film exposure. This technique has been considerably improved in recent years.

Sonnabend¹⁰⁶ claimed that proper use of ultraspeed film, intensifying screens and filtration could reduce gonadal exposure to a range of 0.01 to 0.10×10^{-3} mr.

It should be noted that Jung⁵³ has pointed out that the gonadal doses as currently measured are actually lap doses and that the actual germ cell dose is something less than one tenth of that, which has been measured. These results have been obtained with He agrees with Richards that the gonadal dose received by children are somewhat different if for no other reason than the closer

Authors.	kvp	mA	Added filter mm. al	HVL mm. al.	Field dia.cm. // Target dist. cm.	Output rsec.
Nolan 1935	65	10	0			3.2
	45	10	0			4.5
Stanford and vance 1935	65	10	0	11.0		2.1
Budowsky and co-workers. 1956	65	10	0.55			
Bailey 1957	60		0	11.0	6.4/20	2.2
	60		110	11.7	6.4/20	11.2
Blackman and greening 1957	60		0		11/20	
	60		0		6.1/20	
Webster and Merril 1957	65	15	11.0		7.5/20	2.1
Etter and co-workers:	65	10	0			
	70	100	2.0			
Lanson 1958	55					
Richards. 1958	65	100	11.75		6.9/117.55	0.85

Some previous investigations

Table 3 continued next page.

Numbers of films	Total time of exposure sec.	Gonadal dose testes	ovaries	Eye dose	Dose to side of neck r	Max. skin dose	Thyroid dose
28	75						
25	70				75		
14	14	4.76	0.84				
14	41					76.9	
14	44						0.86
14							11.11
14				32	117	45	26
14				21	4.8	20	
10	110	8.0	11.0				
14	26.3	11.5	22.1		35.6		34
14	10.4	10.7	17.4		5.5		5
12-14		0.8					
11	28	2.14				6.5	

Table 3 continued from previous page.

Table 4 Gonadal doses obtained by other investigators resulting from complete roentgenographic examinations.

Investigator	KVP	Ma	Total time	Films	DOSE	
					male mr	Female mr
Stanford and Vance 1955					3.4	0.6
Budowsky and co-workers 1956	65	10	41	14	450	lap
Osborn and Smith 1956					4.75	0.8
Hell 1957	50	8		12	4.6	
Webster and Merrill	65	15	10	10	8.00	11.0
Etter and coworkers 1958	90	15	1.2	14	11.0	1.0
	70	10	10.4	14	10.7	17.4
Hammer and Jacobson 1958	58	8	118	115		8.00
Kirsh 1958	60		9.8	112		5.110
Larsson 1958	55	3.6		13	0.8	
Richards 1958	65	100	28	14	2.8	
Taft 1958	65	115	9.33	110		110.5
Bjarngard and coworkers. 1959	60			14	0.9	0.4
Sonnaibend 1960	60	10	28	111		0.9

proximity of the gonads to the head and neck areas to be radiated.

Jinks⁵² has reported that by the proper use of X-ray techniques and a leaded cloth over the pelvic region, a 98.23 percent reduction in radiation to the child's reproductive organs can be achieved.

Williamson and Williams¹²³ stated that the average gonadal dose to children, using a variety of X-Ray techniques, was 0.85 MR per pair of bitewing exposures. The result obtained with a long cone, fast film technique however, was 0.1 to 0.2 MR which represented a considerable reduction.

Interesting summaries of data pertaining to gonadal exposures obtained by various authors have been presented.

Bjanngard and Associates²⁴ in Table 3 gives a list of values ranging from 0.8 mR to 22 mR.

Wainwright's summary indicates a range of 0.005 to 15.0 mR per film¹³¹.

However, the newer radiological techniques and particularly ultraspeed films would seem to invalidate results obtained as recently as 10 years ago. Wainwright reported that the average gonadal dose per film using newer techniques was 0.05 mR.¹³⁰

No dentist needs to allow his dental patients to receive gonadal radiation doses anywhere near the recommended maximum dose of 500 mR during the reproductive years (10 to 40 years of age).

However, Menczer⁷¹ has reported that dentists in the Hartford, Connecticut area in 1963 delivered from 8 to 88 mR to the gonads in routine surveys and their attitude towards potential radiation hazards was poor and unconcerned.

Using Wainwright's¹³⁰ figure of 0.05 MR per film, this would allow the dentist to take 10,000 dental films during the 30 year period or at an average of more than three hundred per year.

These figures should not encourage complacency. Many dentists use faulty techniques with faulty machines, so there is much reason for improvement in order to reach Wainwright's figures.

Richards¹⁰⁰ indicates that 46 complete roentgenographic examinations of an adult man would expose his reproductive cells to about 100 mR, the same negligible amount that he will receive from testing of atom and hydrogen bombs in 30 years. It should be noted that women receive even less irradiation of the reproductive cells than do men. While in comparison every day peoples' bodies receive 0.4 mR of exposure from cosmic rays from the heavens above and from radioactive minerals in their bodies and in their environment. In the course of 30 years, exposure from these natural sources of radiation will amount to approximately 4300 mR.

5.7 Somatic Effects.

It is convenient to think of the somatic effects of ionizing radiation as subdivided into two groups.¹⁴

1. The early or acute effects are characteristically the result of a single massive dose.

2. The delayed or late effects which may occur as a result of a single massive dose or after the accumulation of many minor exposures. This latter group is of primary concern to the dentist as he is dealing with multiple small doses.

The essential biological principle employed by the dentist who uses ionizing radiation in dental diagnosis is that tissue and cellular repair occurs following radiation damage.¹⁴ If sufficient time elapses between the administration of doses of ionizing radiation, tissue recovery can be complete. However, it must be stressed that recovery - even full recovery does not mean that irradiated cells are unaltered by irradiation. The capacity to reproduce may be fully restored but other functions of these cells may be permanently changed, which could then manifest in decreased tissue tolerance in dietary changes trauma, infection and foreign chemical substances.

The long term somatic effects of radiation need to be considered. Carcinogenesis and leukaemia have been

particularly studied in this regard. The magnitude of the risks is very small in medical and dental radiology - the probability of a thyroid carcinoma resulting from a single irradiation of an individual is 1 to 5×10^{-6} rad⁻¹ over a 10 to 20 year period;¹²³ or expressed in another way, a prevalence in a population of one million persons of 10 to

Age group at time of the bomb	Dose (rad)	Exposed		Control		Refer- ence
		Examined (No.)	Affected (%)	Examined (No.)	Affected (%)	
≤ 30 years	200+	94	34	94	1	(5)
Over 30 years	200+	77	61	90	16	(6)
<i>In utero</i>	100+*	38	39	48	4	(7)
Not yet conceived	150+*	103	0			(5)
Not yet conceived	100+†	25	0			(8)

Table 5 Frequencies by age group of complex cytogenic abnormalities among Japanese survivors of the atomic bombs.

* Maternal dose

† Dose received by at least one parent

Gestational age (week)	Total number exposed*	Total number examined	Number with small- head circumference†	
			Mental retardation	Normal intelligence
≤ 15	57‡	56‡	9	14
> 15	109	105	28	4 ¶

Table 6 Effects of intrauterine exposure to the Hiroshima atomic bomb.

* Exposure within 1800 rads at the hypocenter.

† Circumference 2 or more standard deviations below average.

‡ Excludes 2 with pre-existent Down's syndrome.

Exposed at 11 and 24 to 18 weeks respectively.

// Exposed at 16, 32, and 36 to 40 weeks respectively.

20 cases. The data on which this estimate was based concern cases where the doses have been in excess of 20 rad and the radiations were received at high dose rates.

To the individual this is a very small risk compared to other more common hazards of life. For example, the risk from injury and death from road accidents reported in New Zealand arranged over the whole population would be about 8×10^{-3} per capita per year.¹²³

5.8 Cytogenic Abnormalities.

In Table 6 are summarized the results obtained in a series of studies of chromosomal abnormalities by age group of individuals exposed to the atomic bombs in Japan.

1. When the dose received was at least 200 RAD by an age group of 30 years or younger, 34 percent had complex cytogenic abnormalities. 20 years later as compared with 1 percent of the controls.
2. The percentage of individuals so affected who were 30 years old at the time of the bomb were almost double the percentage for the younger group and 4 out of the 77 individuals in the older group had clones of cytogenetically abnormal cells.

3. The complex chromosomal aberrations which occurred with increasing frequency among persons who had been over 30 years old at the time of the bomb consisted of translocations pericentric inversions, deletions, chromatid exchanges and centromere breaks.
4. Among persons who were in utero at the time of the bomb and whose mothers received a dose of at least 100 rad, 39 percent displayed complex chromosomal abnormalities as compared with 4 percent of the controls.
5. These abnormalities were found even among persons exposed during the first trimester in utero. No such effects were found in the child in preconception irradiation of either parent.

Cytogenic Abnormalities at Low Levels of Radiation.

At the cellular level there is experimental evidence which indicates that low levels of radiation down to 0.25 rads
128
produce changes in the somatic cells.

The everted cheek pouches of Chinese hamsters were given graded doses of X-rays for 30 mins. From biopsies the

frequency of chromosomal breaks were recorded.

TABLE 7

Radiation	Breaks/100 metaphase	
0.25 R	12	"
0.3 R	24	"
5.25 R	35	"
No irradiation	4	"

Although the relationship between radiation dose and chromosomal breaks was linear it was not proportioned to the dose.

This experiment gives further evidence that there is no threshold level below which cellular effects of X-radiation is absent down to 0.25 rads.

Assuming that this effect also occurs in man at these low dose levels then how can the lack of clinical evidence be explained? This is probably due to the inherent ability of the tissue to undergo molecular repair and also due to the rapid cell proliferation and exfoliation normally present in this tissue.

5.9 Developmental Defects.

The irradiation of the fetus has been purported to be teratogenic in man. In the observations of the effects of the atomic bombs on pregnant women in Japan it was noticed that the radiation effects were in relation to the stage of development of the fetus.⁶⁵

1. The effects among the children of the women who were exposed within 15 weeks of their last period. Of the 56 examined in this category born to mothers who had been within 1,800 meters of the hypocentre, a diminution of head circumference was observed in 23 per-cent. Of this number 9 were mentally retarded.
2. Among the 105 individuals exposed in utero more than 15 weeks after the mother's last menstrual cycle small head circumference was observed in 6 of which 2 were mentally retarded.
3. Anthropometric determinations were obtained on about 2,400 children now 6 to 19 years who were exposed to the radiation, and comparison was made to equal numbers who had not been exposed. Multivariant analysis revealed that as the

Table 8

Distance from hypocenter (meter)	Retarded (No.)		Normal (No.)		Total exposed*
	Head cir- cumference > 3 S.D. below mean	Head cir- cumference - 2 to - 3 S.D.	Head cir- cumference > 3 S.D. below mean	Head cir- cumference - 2 to - 3 S.D.	
≤ 1200	6	2	1	1	11
1201-1500	0†	0	2	6	23†
1501-1800	0	1	0	5	23†
1801-2200	0	0	0	0	21‡

Table 8 Radiation effect on head circumference and intelligence following intra uterine exposure to the Hiroshima atomic bomb within 15 weeks of the mother's last menstrual period.

* Some children in the study were normal with respect to intelligence and head circumference; thus the number in columns 2 to 5 do not add up to the totals in column 6.

† Excludes two with preexistent Downs syndrome.

‡ One not examined.

3. (cont'd) radiation exposure increased there was small but statistically significant decrease in body measurements at all age levels and in growth rate at post pubertal age levels.

These variations may not be due entirely to radiation as there were other factors like economic loss due to fire and blast.

Brown¹² has reported a case of absence of teeth due to early irradiation.

Bruce and Stafne¹¹ studied the effects of irradiation therapy for pathological processes occurring in proximity to the developing dentition in 5 cases and made the following observations :-

1. Irradiation therapy can injure a tooth germ to the extent that a tooth will not form.
2. Causes dwarfism of the roots of the permanent teeth that are undergoing development during irradiation.
3. Premature completion of calcification.
4. May cause early eruption of permanent teeth.

David Bixler¹⁴ from the writings of Pollard and Little has

made the following observations which will be of interest to practitioners of dentistry.

1. X-ray doses much greater than 100 R such as used therapeutically, constitute a powerful teratogenic agent with deformities of the head, limbs and spinal column.
2. Doses less than 100 R such as are used for diagnostic purposes, are not unequivocally without teratogenic effect even though the proof of teratogenecity has yet to be accomplished.

5.10 Oral Mucous Membrane.^{90 67}

The effect of radiation on the oral mucous membrane has been observed during the treatment of oral neoplasms. In fact, the radiologist uses the oral manifestations as a clinical guide to the effectiveness of the radiation therapy.

The stratified squamous epithelium lining the oral cavity is moderately radiosensitive. Increased keratinization of the oral mucosa is one of the first changes that appears. This radiation induced leukoplakia is the result of a slower desquamation and more complete maturation of the cells than would normally occur. In time the mucosa becomes thin because the basal layer has been

destroyed and the maturing cells that have been desquamated have not been replaced. The oral mucosa becomes eroded and appears erythematous.

The oral epithelium does not respond in the same way in all locations. The response becomes more severe week after week and the effect of radiation is more intense on the side of the port of administration, although the remaining oral tissues are also affected.

1. The radiation effect during the first week of therapy is a reddening of the buccal mucosa.
2. During the second week, white patches on the mucous membrane of the lips, cheek, and tongue may be evident.
3. By the third week, the sides of the tongue begin to show evidence of severe irritation and epithelial sloughing.
4. After the fourth and fifth weeks of radiation therapy, the lips and corners of the mouth may begin to show an ulcerated appearance.

Following cancericidal doses of radiation given by the use of conventional techniques, the mucosa usually heals promptly. After the irradiation of large tongue lesions however, it may take a month or more for complete healing to occur. There are several

post-irradiation changes in the sub mucosa.

Lui⁶⁷ holds similar views, that the successful confinement of irradiation to a small tissue volume and the effective activity of the reparative system are important factors in limiting the damage and in permitting recovery.

5.11 Salivary Glands.^{90 67}

Irradiating lesions of the oral cavity have frequently damaged the salivary glands as well as the small mucous glands of the mucosa. These effects are usually evident by the second week of radiation therapy.

1. The volume of the salivary secretions becomes diminished.
2. The saliva becomes more viscous.

This alteration in quality and quantity of saliva makes it difficult for the individual to swallow food and it also affects his speech as a result of the dryness of the mouth. Normally the volume and character of the saliva allow for proper maintenance of the oral environment. The change in the saliva induced by the irradiation results in a considerably less effective mechanism. Complete function never returns when a patient receives a cancericidal dose.

5.12 Teeth.

Defects in human tooth enamel following high dose irradiation

tion to the head and neck have been reported. Two alternative explanations have been favoured.⁹⁰

1. That radiation directly alters the susceptibility of teeth to carious destruction.
2. That radiation causes salivary dysfunction which in turn produces xerostomia, a condition associated with increased carious activity.

Walker¹²⁷ listed the direct effect of radiation on the solubility of enamel and dentine in lactic acid, a primary factor in tooth decay in vivo.

Results :- 26 non carious teeth were cleaned and hemisected. 50 percent of it was irradiated.

The range of weight loss for control sections was 0.0140 to 0.0239 gm.

The range of weight loss for irradiated sections was 0.0160 to 0.0237 gm.

The results suggests that therapeutic irradiation does not significantly affect the susceptibility of teeth to demineralization in vivo.

However, these observations do not rule out other possible direct effects of radiation.⁹¹

1. Increased tooth fragility caused by protein degradation.
2. Unilateral radiation induced demineralization.

Karmioli and Walsh⁵⁵ studied 5 cases of dental caries after radiotherapy. These were all treated for oral malignancies with radiation doses between 5,000 and 6,000 rad of ⁶⁰C teletherapy for epidermoid carcinoma. The observations made were -

1. Massive widespread loss of tooth structure, beginning initially with the enamel and then proceeding to softening and loss of dentin. The buccal or lingual surfaces, and the incisal and occlusal surfaces are all involved.
2. Normally immune areas such as the tips of the cusps of the posterior teeth are equally affected.
3. The last areas that seem to be effected and lose their enamel are those at and just below the contact points. These areas are usually some of the first areas to be affected in ordinary smooth surface caries.
4. Mandibular anterior teeth which are usually the most resistant to caries are equally if not more affected and may be affected earlier than the other teeth. Further, the mandibular anterior teeth which were extensively involved in this process were not in the field of radiation of any of these patients.
5. The significant common factor in all the cases was the inclusion of the major salivary glands in the field of radiation.

These results seem to be due to an alteration of the volume and character of the salivary secretions. Similar destruction of teeth have been described in cases of congenital dysfunction of major salivary glands.¹⁴⁴

The therapeutic doses described earlier have been measured in thousands of roentgens while in oral diagnostic examinations, far smaller doses are used. In man no such sequelae to diagnostic radiography has been reported.¹⁰⁰

5.15 The Skin.

The skin of the face is the first tissue exposed in an oral examination. Excessive exposure of the skin to X-radiation may result in an erythema, or reddening of the skin, which is produced by dilation of the small blood vessels beneath the skin. The erythema may follow a few hours after exposure of the skin.¹⁰¹ After several days pigmentation of the skin may replace the erythema. The pigmentation phase may continue for a few weeks to several months.

The dosage of X-rays that will produce the threshold erythema in human skin is reported to be between 165 and 350 r.^{67,86,101} It is known that an exposure to fewer roentgen units is sufficient to produce erythema of the skin when radiation of long wavelengths, rather than that of short wavelengths is utilized.

A preponderance of shorter wavelengths can be achieved

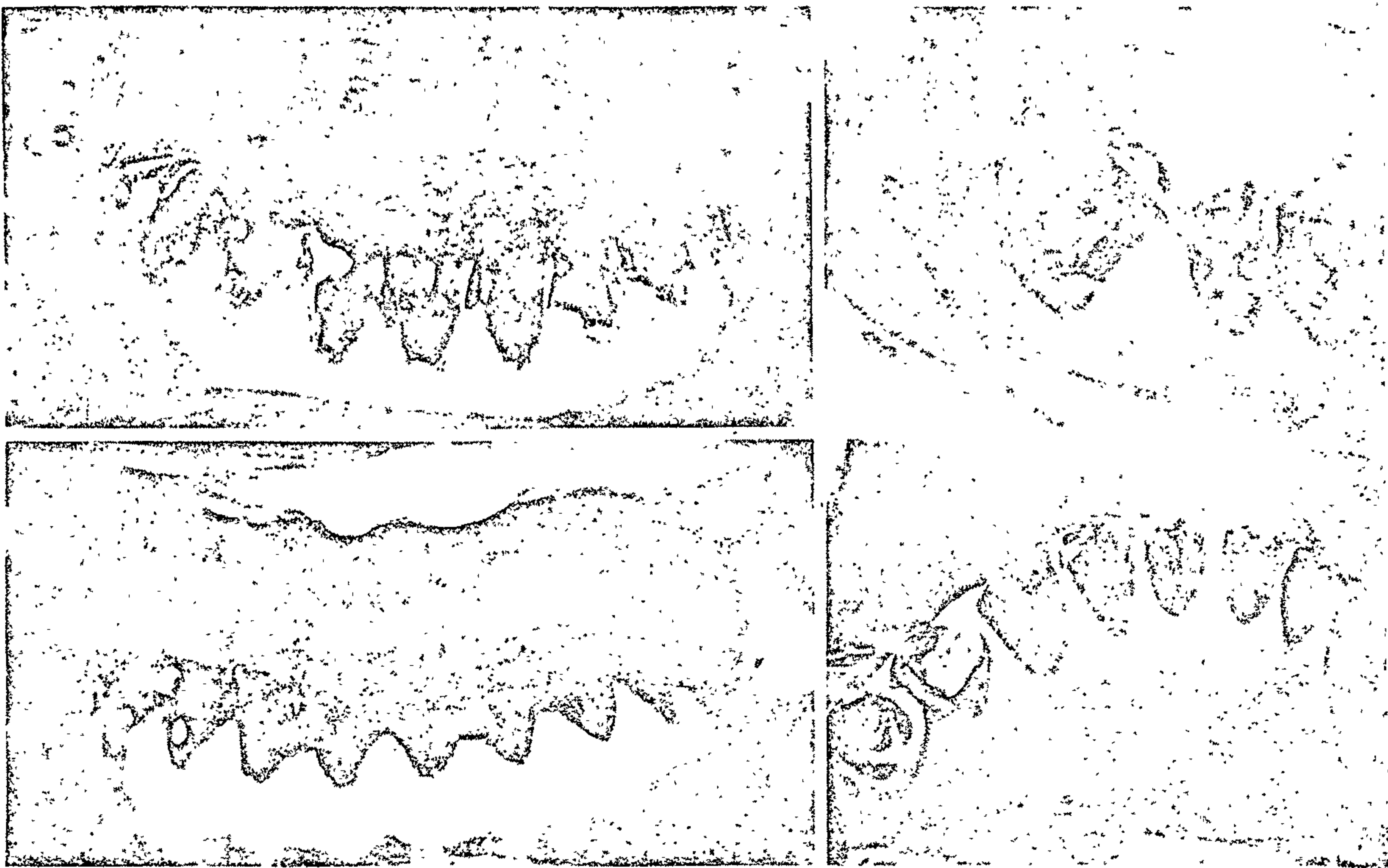


Fig 3 ■ Case no. 1. Top left, radiation caries of mandibular anterior teeth five months after completion of radiotherapy, with massive loss of enamel and deep staining of dentin. Top right, mandibular posterior teeth with irregular loss of enamel. Explorer demonstrates softening of dentin at tips of cusps. Bottom left, three months later, almost all remaining enamel has been lost, dentin is more deeply stained, surfaces are rougher and softer, and crumbling of incisal edges is proceeding at accelerating rate. Bottom right, mirror-image lingual view at this time.

3

Effects of Irradiation on Teeth

in an X-ray beam by the application of higher voltages to the X-ray tube or by filtration of the X-ray beam. Approximately 50 additional roentgen units of radiation are necessary to produce the threshold erythema for each additional millimeter of aluminium that is added as a filter.

The rate of recovery of the human skin from the effects of X-ray irradiation has been found to range between 46 and 77 percent during the first days^{67 88} with the percentage of recovery increasing with time.

In 1957 Cade²⁶ reported, a search of the world's literature uncovered less than 300 reports of cancer induced by radiation. The doses of radiation received by many of the patients were unknown, but when dosages were cited they were measured in thousands of roentgens. There were no dental patients among these patients.

The range of total dosage of radiation to which the patient's face is exposed during the complete periapical examination is reported to be between 5 and 315 r (measured in air).^{73, 102} The wide difference between these two values is due to the different number of exposures, the different amount of filtration, and the different speeds of films used in making the examinations.

Budowsky and Associates⁸ have reported that the facial area most heavily exposed to radiation during a complete periapical examination is the skin in the area of the maxillary premolars. When 14

slow speed films were exposed to a large unfiltered beam of radiation, this area received between 55.9 and 91.6 r with 76.9 r as the average exposure. Richards¹⁰² data indicate that the dose can be reduced to 1.5 r when films of highest speeds are exposed to a small, carefully filtered beam of the exposure of this area of skin would be closer to 6.5 r.

A comparison of the threshold erythematous dose with the maximum diagnostic exposure of the skin reveals why erythema is never seen in patients and also reveals that techniques which use high speed films collimated filtered beams afford the greatest safety to the patient. A similar comparison between the proved carcinogenic dose and the maximum diagnostic exposure of the skin perhaps reveal why there are no reports of oral malignancies attributed to exposures from dental roentgenographic procedures.

Although many millions of dental roentgenographic examinations have been made, no instance of X-ray burns or of facial or oral malignancy resulting from diagnostic dental X-ray procedures have been reported. In the light of this enviable record, plus the fact that far smaller amounts of radiation are being used at present in X-ray examinations of the teeth, no patient need be apprehensive about the possibility of these two effects of radiation occurring following periodic oral X-ray examination.

In 1940 Levin and Behrmann⁶³ reported a case in which pigmentation of the face developed thirty six hours after an X-ray examina-

tion of the patient's jaw. The patient was a 19 year old girl, the daughter of a white mother and a full blooded Negro father. The exact roentgen dosage to which the patient's face had been exposed was not known, but it corresponded with that used in the examination of thousands of other patients. The pigmentation appeared without a preceding erythema or other subjective or objective symptoms. It was thought that biologic factors such as race, colour, age and endocrine status were of much greater importance than the roentgen dosage in the production of the lesion. It was thought also that the pigmentation would disappear within several months without any sequelae. No case similar to this one has ever been reported in the literature.

Some dentists still persist in the hazardous practice of holding film packets in the patient's mouth while the X-ray equipment is operating. This foolish practice has caused some of them to suffer radiation dermatitis of their fingers, others to lose their fingers or hands, and still others to lose their lives from from radiation induced cancer.^{68,143} At the Mayo Clinic, a study of 194 patients with chronic X-ray dermatitis of the hands showed that in 31 percent of the patients the lesions underwent malignant degeneration¹⁴³. In some hands it took as long as twenty years for the malignant degeneration to develop. There is no record of the patient's fingers suffering damage from radiation because he held film packets within his own mouth. The infrequency of this action by the patient accounts for the absence of damage to his fingers.

Table 9

Examination	Skin	Eye ball dose mrad
Full mouth survey 14 films	550	90
Bicuspid molar region -- bitewing	550	4
Maxillary incisors-- occlusal	1100	30
Maxillary incisors-- periapical	550	4
Full mouth survey		
Panoramic X-ray machines	300	4

Some typical radiation doses to patients during dental x-ray examinations, as measured on a Rando patient equivalent phantom. by Williamson
1122

5.15 Effect on the Eyes.

In 1963 and 1964 ophthalmologic examinations were made on atomic bomb victims in Japan.⁶⁵

40 percent of those who had received doses in excess of 200 rad had significantly more axial opacities. Most of these lesions were small and only one was regarded as a mature radiation cataract. A dose response relationship was demonstrated. In a previous similar examination less than a dozen survivors were classified as having severe radiation cataracts and in none was visual acuity worse than 20/70. In a more recent survey among children who were in utero at the time of the exposure to the bomb a similar relationship was suggested.

Though opthalmic effects of irradiation have been noted among atomic bomb survivors, impairment of vision has been relatively mild or rare.

Medical literature contains numerous reports of cataracts which resulted from X-ray therapy.^{30,69.}

It has been reported that the dose of X-radiation required to produce cataracts lies in the region of 200 to 2000 r. The wide span of this range of doses was explained in part by a study which found that 200 r was the smallest single dose that produced a cataract in human eyes, whereas intermediate values of 400 r and 550 r were the smallest total doses that produced cataracts when the total dose was fractionated over periods of between three weeks and three months and over three months respectively. All patients who received more

than 1150 r to the lens irrespective of the duration of treatment developed cataracts.

Evans in a study reported by Richards¹⁰⁰ claims that the eyes of young experimental animals irradiated during the prenatal or early postnatal period show a greater sensitivity to radiation than do the eyes of older animals exposed to the same dose. The lens of the human eye exhibits the same extrasensitivity until the age of 1 year.⁶⁹

Blackman and Greening¹⁰ using 60 KVP without added filtration and the two field diameters of 11 and 6.1, target distance of 20 and 14 films obtained an eye dose of 32 and 21 r respectively. Since then with improved techniques these doses have been reduced.

Antoku et al.² using 60 KVP F.S.D. 15.5 cm, 0.5 mm Al. added filtration and varying diameter showed that the dose could be reduced to 263 mR for a full month radiograph. Table/9.

Jermain et al.⁵⁴ reported doses of 90 m.rad to the eyelid during a full month, intraoral examination and 36 m. rad for a panoramic plus bitewing technique.

These doses to the eyes are some orders of magnitude smaller than those generally believed to be required for the induction of lens opacities.

There is considerable concern about the cumulative effect¹⁵ of radiation exposures to the eyes because the lens of the eye is unique in that its cells are not eliminated but remain within the lens

Table 10 Doses (millirads) to body sites in a phantom

during full mouth radiography at 60 kvp, FSD 15.5;

0.5mm. aluminium added filtration

Sites	* Fourteen films 95 Ma.S 6.5cms 8.0cms 10.0cms			# Sixteen films 111 Ma.S 6.5cms 8.0cms 10.0			# Eighteen films 127 Ma.S 6.5cms 8.0cms 10.0		
Lens.	263	11250	1770	271	1250	1800	277	1270	1830
Pituitary fossa	14	30	75	18	31	75	21	36	85
Thyroid gland	342	1180	1880	372	1250	2030	428	1380	2470
Skin	112360	12660	12210	14440	14470	16900		16820	16400

* No bitewing

Two premolar bitewings, two molar bitewings

capsule during the life of the individual. Most cells which have received radiation exposure to the extent that there may be latent damage can be removed from the body before the damage is completed. In the cells of the eye however, this cannot happen. Further, it may take as little as 6 months or as much as 20 years for a radiation cataract to develop.¹⁵

5.15 Haemopoietic Injury.

Moderate whole body irradiation, such as 25 R will produce transient changes in the blood count. Although the blood forming cells may be radiosensitive, they may also have great powers of recovery.

The usual picture of blood injury to radiation is leukopenia which in some cases may go to leukemia. It is very doubtful whether a single case of adult leukemia has occurred from acute doses of less than 200 rads, to the bone marrow. Of the various neoplasms, produced by whole body radiation, the risks of leukemia is the greatest.

In a study of Japanese persons exposed to the atomic energy at Hiroshima and Nagasaki, the incidence of leukemia increased after a latent period of 10 years after exposure. The incidence has declined since then. There is some evidence that low energy dosages directly to the fetus may result in childhood leukemia. However, evidence is limited.

(Table 11) Stewart¹⁰⁷ described a study of 677 leukemic children in England and Wales in which the proportion of mothers who reported abdominal exposure to diagnostic irradiation during the relevant pregnancies was twice the proportion for mothers of normal children living in the same area. A similar difference was reported with neoplasms of other kinds. It is possible that mothers of children with cancer, reported their radiological exposures more fully than the mothers of healthy children did.

MacMahon⁷⁰ avoided this potential bias, in histories obtained through interviews, by studying the obstetric records for irradiation during pregnancy among mothers of 304 leukemic children and 252 children with other cancers as compared with records for a 1 percent sample of all other births in the area. He found 40 percent excess of leukemia and all other neoplasms among children whose mothers records showed diagnostic radiation of the abdomen during pregnancy.

A similar study⁴⁷ produced opposite results at a hospital in Chicago in 1948, where pelvimetry was a routine procedure. A comparison was made between infants exposed to radiation and infants who were not. After a period of 15 years when these children were examined there was no significant increase of leukemia in the children who were irradiated.

Richards¹⁰⁰ noted the effects of low chronic X-radiation and made the following observations. "Large numbers of patients have undergone repeated dental radiographic examinations in the past. The periods of time that have elapsed since then exceed the latent period for the occurrence of leukemia. Yet, in spite of this, the incidence of leukemia has

Table 11 Relative risk of various childhood
cancers following intrauterine or preconception
exposures to diagnostic radiation

Neoplasm	Relative risk*
Intrauterine exposure	
Stewart and Kneale	
Leukemia	1.5
Lymphosarcoma	1.5
Cerebral tumors	1.5
neuroblastoma	1.5
Wilm's tumor	1.6
Other cancer	1.5
MacMahon	
Leukemia	1.5
Central nervous system tumors	1.6
Other cancers	1.4
Graham et al	
Leukemia	1.4
Preconception tumors due to exposure	
Graham et al	
Leukemia	
Mother exposed	1.6
Father exposed	1.3

* Relative risk in controls = 1.0

declined steadily for the past 20 years. The occurrence of leukemia as a result of dental X-radiation does not need to be feared greatly by the dentist or the patient.

5.16 Thyroid Gland

Cancer of the thyroid gland has been reported in a few instances among many children who were given X-ray therapy (200 to 800 r in air) directly at the head, the neck, and the region of the thymus gland. This suggests that the child's thyroid gland is specially sensitive to irradiation.^{81,92,109} Doses of less than 180 r to the thorax of children have been found not to produce malignant tumors in the glands of these patients.⁹² The adult thyroid gland must be less sensitive to irradiation than the child's for very few cases have been reported of thyroid cancer developing in patients who had received thyroid irradiation during adulthood.⁴⁶

(Table 12) Calculations made with the data provided by Baily²³ and Bjarngard²⁴ relating to the exposure of the thyroid indicate that less than 1 percent of the total dose received by the face during a fourteen film periapical examination is effective at the thyroid gland. The exposure of the thyroid gland would be larger, if X-ray beams of larger diameter were used.

No studies have been made in an attempt to prove or disprove an association between dental exposure of the thyroid gland and malignancy of the gland.¹⁰⁰

If small exposures of the thyroid gland to radiation during dental X-Ray examinations has caused damage to the gland in the past (and this has not been proved) it is far less likely to occur in the future because of the greatly reduced amounts of radiation that are currently being used in dentistry.

5.17 Ageing.

It has been demonstrated that the life span of a small laboratory animal can be shortened by exposure of the animal's entire body to X-radiation. Some data indicate⁵⁶ that the reduction of life span is proportional to the total dose. However, some careful longevity studies with mice have shown an increase in the average life span at low chronic doses; others have shown that shortening of life actually is not proportional to dose.^{6,7} Decreased longevity of American radiologists has been reported by one observer¹²⁶ and denied by others.^{110,115}

The life expectancy of British radiologists was found to be similar to that of other men of comparable social status and has not been altered substantially by occupational exposure to radiation.

(Table 12) Experiments with mice exposed to 300 to 1,800 r have shown for a given tissue dose that partial body exposure was much less effective than whole body exposure in the shortening of life.⁵⁶ Extrapolation of the data for partial body exposure suggests that at still lower doses (for example, exposure at 100 r) the

effectiveness per unit dose may be so reduced as to be negligible. The doses tested in this study on mice are hundreds to thousands of times greater than those used in human roentgenographic diagnosis. Moreover, the total dose accumulated from repeated diagnostic exposures is fractionated and therefore presumably of diminished effectiveness.⁵⁶

A statistical study of the longevity of dentists⁷ indicates that dentists live almost three years longer than white non-dentists. The result of this study must not be construed to indicate that the dentists' daily small occupational exposures to X-radiation has lengthened his life span; instead, these data indicate that apparently the dentist's life expectancy has not suffered because of his slight occupational exposure to radiation.

In the light of the evidence presented, neither the dental patient nor the dentist needs to worry seriously that his contact with X-radiation in the dental office will have any effect upon his life span. The evidence, however, is by no means complete.

5.18 Sterility.

Sterility results from the destruction by X-radiation of the gonadal tissues which produce mature sperm and ova. Whether the tissue destruction and the subsequent sterility are temporary or permanent depend on the dose of radiation received by the gonads.

Changes in sperm count in the dog can be noticed if 0.5R

Treatment	Integral dose (kg r)	No. of mice	Mean survival time $\pm$ SE (days)*	Decrement in life span per unit dose	
				day/100 r	day/kg r
Control		34	676 $\pm$ 25		
300 r, WB	7.8	35	549 $\pm$ 24	42	16
500 r, WB	14.6	43	556 $\pm$ 23	21	8
1200 r, WB (4 $\times$ 300 r)†	31.2	43	429 $\pm$ 21	21	8
750 r, bilateral thorax	6.3	34	661 $\pm$ 26	2	2
1800 r, right thorax	7.7	20	567 $\pm$ 39	6	14
600 r, right thorax + pelvis	5.6	38	660 $\pm$ 23	3	3
1200 r, right thorax + pelvis	11.1	40	583 $\pm$ 28	8	8
1800 r, right thorax + pelvis	16.7	20	501 $\pm$ 37	10	10

Table 12 Survival of female mice after whole body and partial body exposure.

* Mean ages may be determined by adding 170 to the mean survival times. SE, standard error of the mean survival times.

† The tabulated figures referring to survival and life span decrement are based on the time elapsed from the beginning of irradiation. Computed from the day on which the final 300 r fraction was given, the last 3 columns of this row would read 387 $\pm$ 21 days/100 r and 9 days /kg r respectively.

Cause of death	Mean age at death		
	Dentists	Dentists age adjusted	White male over 24
Diseases of the circulatory system	67.6	69.1	68.0
Neoplasms	66.6	67.7	65.2
Diseases of nervous system and sense organs	70.8	72.1	70.6
Accidents poisoning and violence	60.9	61.8	63.4
Diseases of digestive system	64.0	65.4	61.6
Diseases of respiratory system	72.0	74.2	67.9
Diseases of urogenital system	70.6	72.3	69.2
Allergic, endocrine, metabolic and nutritional diseases	69.9	71.0	65.6
Infective and parasitic diseases	63.3	64.4	57.7
Senility and ill-defined conditions	70.8	74.6	69.0
Mental, and psychoneurotic disorders	63.5	63.9	55.3
Diseases of blood and blood forming organs	63.3	63.0	68.2
Diseases of bone and organs of movement	74.1	74.3	64.4
Congenital malformations	57.0	57.4	49.0
Skin and cellular tissue	63.7	62.7	64.8
All causes	67.5	68.9	66.1

Table 14 Mean age of death according to cause of death

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is given for a long period of time. However, it takes as much as 4.4 R per day exposure to female mice over a long period of time to produce sterility.⁵⁹

It has been reported that an estimated 400 r in a single acute dose to the male gonads will produce permanent sterilization whereas the sterilization dose in the female may be more than 624 r (effective at the ovaries).⁵⁰

No data ~~are~~ available regarding the amount of chronic exposure that will produce either temporary or permanent sterility in human beings. Presumably because of repair that occurs in gonadal tissues, a greater total dose of radiation from chronic exposure than from an acute exposure would be necessary to produce sterility.

In contrast to the dose that will produce sterility, the exposure of the male gonads resulting from complete dental X-ray examinations has been reported to range from 0.00043 r to 0.07 $\frac{100}{r}$.^{100,105} The probability that sterility might result from the amount of radiation that the gonads receive during a complete oral examination is therefore extremely remote. Even the annual repetition of the X-ray examination would not significantly increase the possible occurrence of permanent sterility in the male patient. Because of the shielded location of the ovaries, the gonads of the female patient receive about 18 to 44 percent as much radiation from oral X-ray examinations as do the male gonads.¹⁰⁵

If a dentist is conscientious about limiting the exposure of his own body and gonads to no more than the current official permissible exposure of 5 R per year, he never need fear that sterility will occur because of his occupational exposure.

6. FACTORS IN RADIATION EXPOSURE AND DIAGNOSIS.

In radiation roentgenography it is desirable to use techniques that require the smallest amounts of radiation to produce roentgenograms of the highest diagnostic quality.

The only reason¹¹¹ for exposing the dental patient to any roentgen ray radiation should be to obtain maximum amount of diagnostic information regarding his dental health and as an aid in treatment. The utilization of techniques that require very small amounts of radiation to produce roentgenograms of only mediocre quality is as undesirable a technique as that which requires unnecessarily large amounts of radiation to produce roentgenograms of high quality.

The amount of radiation¹⁰⁰ delivered to the patient during the taking of roentgenograms depends on the following factors :-

1. The energy of the roentgen rays.
2. The focal distance (distance between the tube target and the skin).
3. The amount of filtration.
4. The amount of current.
5. The total time the patient is exposed.
6. The type of collimation.
7. The type of film.

6.1 Kilovoltage.

It is the energy of the roentgen rays (KVP). It is the

major factor in determining both the rate at which the radiation is being delivered and the depth of penetration. The kilovoltage or the kilovoltage peak refers to the potential difference between the anode and the cathode of the X-ray tube.

1. Higher K.V.P. have shorter wavelengths with more penetrating power.
2. The contrast of an object seen in a radiograph is affected by the kilovoltage. The lower the K.V.P. the greater the contrast and the higher the K.V.P., the longer the scale of contrast.
3. Increased kilovoltage increases the amount of scattered radiation and this reduces the visible contrast of the radiograph through the production of film fog.

Several studies have been carried out to observe the effects of varying KVP on the dose to the patient in diagnostic radiography and also to observe the effect on the quality of the radiograph.

In Nolan's experiment⁷³, the X-ray machine was operated at 65 KVP, 10 milliamperes, no filtration and an 8 inch focal distance. The number of exposures for a full mouth examination was 28. The total exposure time was approximately 75 secs. The total dose delivered to the region was 238 r. When he operated the

machine at 45 KVP, 25 films for 70 secs., total dose was 315 r. His data showed 12.6 roentgens per film at the facility using 45 KVP, and 8.5 roentgens per film at the 65 KVP facility.

Reduction of skin exposure to the dental patient by using higher kilovoltage was studied by Etter.⁴⁰ Using a conventional 60 KVP technique he obtained a mandibular molar radiograph with 16.2 roentgens skin exposure to the patient. With all other variables except for progressively decreased exposure time, the peak voltage was increased to 65, 70 and 75 and skin exposure of 13.8, 10.1 and 10.6 roentgens were measured. The effect of the higher kilovoltage, therefore was to decrease skin exposure substantially by percentages ranging from 14 to 31.

The role of peak kilovoltage in reduction of skin exposure to the dental patient was studied by Sweet.¹¹² Using ultraspeed X-ray film, he found that only 14 ma.s exposure was required for a fourteen film intraoral survey with a 90 KVP technique. This was 58% less than when a 65 KVP technique was used.

In a study of dental X-ray exposures in dental radiography, Richards¹⁰² showed that only 0.36 times as much exposure was needed with a 90 KVP technique as with a 65 KVP technique to cause a thickness of 8 mm of aluminium to be recorded as a density of 1.0 on Radiatized film.

Using Kodak No screen film No.4 Weuhrmann and Monacelli¹⁴⁰ presented data showing the milliamperere-seconds exposure necessary to

produce a constant film density through varying thicknesses of aluminium at varying peak kilovoltage levels. At 50 KVP, 36 Mas exposure was required; 16 Mas. exposure was required at 70 KVP and 10 Ma.s. exposure was required at 90 KVP to produce a uniform film density on transmission through 8 mm of aluminium. Similar results were obtained by Wenhrmann and Curby.¹⁴¹

When Spangenberg and Pool¹¹³ related film density to aluminium penetrometer thickness for various X-ray energies, they found that the radiation dosage required to produce equivalent densities was less at 90 KVP than at 70 KVP.

From the reported findings of O'Shaughnessy and Mitchell⁸³ one could calculate that a fourteen film series of intraoral radiographs made at 70 KVP requires approximately 70 roentgens of skin exposure to the zone of primary irradiation. A similar series made at 90 KVP would require about 10 roentgens of skin exposure.

The above studies have all taken into consideration the skin dose but not the absorbed dose.

Wainwright¹³⁰ found that while the skin exposure and depth dose decreased in the 1 inch of tissue on the tube side of an intraoral dental film with increased KVP the absorbed dose increased in the 3 inches of tissue beyond the film. Therefore he concluded that an increase in peak kilovoltage did not decrease the total patient dose when an effort was made to keep the integral dose as low as possible.

In an investigation of skin exposure, VanAken and Vander-Linden¹²⁰ reported 1.5 roentgens of exposure delivered by means of a 50 KVP technique and a 0.36 roentgen from a 75 KVP technique. The absorbed dose was 0.15 rad for the 50 KVP technique and 0.062 rad at 75 KVP. They concluded that the reduction in absorbed dose was not so great (60 percent) as the reduction in skin exposure (75 percent).

Kort⁵⁷ in a similar study stated that tissue absorption of X-radiation was inversely related to the energy of the source of the radiation. He used high and low energy sources to demonstrate this point and showed that 5.6 times more of the low energy was absorbed than that which was absorbed from the high energy beam.

Kilovoltage peak and Image

Wilsey¹²⁵ exposed aluminium stepwedges to various kilovoltages and found that radiographs produced at lower kilovoltages showed increased contrast in the intermediate blackenings, but this was accompanied by a decreased contrast in the lower and higher blackenings. Radiographs produced at higher kilovoltages showed decreased contrast in the intermediate blackenings. This did not have the advantage of permitting greater latitude or variation from correct exposure and processing because at higher kilovoltages, a wider range of exposures produced the same useful density range.

Fitzgerald⁴² reported that at higher kilovoltages the junction between the enamel and dentine could be visualized better in dental radiographs.

Fuchs⁴¹ pointed out that in Armed Forces as the work load is heavy X-ray technicians' errors were minimized using a high kilovoltage technique as this provided a long scale of contrast. He has also observed that in radiographing chests of military inductees use of higher kilovoltages resulted in better radiographs. Low kilovoltages did not adequately penetrate the chests of average and large subjects.

6.2 Machine Variations

Dental X-ray generators are known to vary in their output when operated at the same kilovoltage and milliamperage factors. It has been said that they vary as much as 250 percent. An implication is that the numerical figures of kilovoltage and milliamperage on the machine dials represent abstract numbers rather than identification of electrical potential at the tube, during X-ray production. This situation creates problems for the practitioner in establishing proper exposure for each new technique. Further, this is not consistent with ideal radiation concepts. Buchholz¹⁹ surveyed 5 machines at a range of KVP and Ma. The wide variations in X-ray output between the dental X-ray generator at predetermined electrical input are complicated by the inability to calculate the output of a given machine when the milliamperage is changed. Failure to achieve diagnostically acceptable radiographs because of machine inaccuracy is frustrating and discouraging. Radiation surveys conducted by the

Table 15 Measured and computed machine outputs in roentgen-minutes

Machine	KV _p	110 Ma. measured	115 Ma. computed	115 Ma. measured
A	50	4.0	6.0	11.5
	60	7.0	10.5	6.2
	70	11.5	17.2	11.5
	80	16.5	24.7	18.5
	90	21.0	31.5	24.0
B	50	1.7	2.5	1.3
	60	5.0	7.5	4.5
	70	7.0	10.5	7.5
	80	10.0	15.0	10.5
	90	13.0	19.5	12.5
C	50	12.5	18.7	17.5
	60	16.5	24.7	23.0
	70	20.5	30.7	30.0
	80	25.5	38.2	38.0
	90	30.0	45.0	46.0
D	50	10.0	15.0	13.0
	60	15.0	22.5	19.5
	70	19.5	29.2	27.0
	80	25.0	37.5	35.0
	90	32.0	48.0	45.0
E	50	7.0	10.5	9.5
	60	12.0	18.0	16.5
	70	18.0	27.0	25.5
	80	24.5	36.7	35.0
	90	32.0	48.0	45.0

National Research Laboratories scientists in New Zealand dental surgeries routinely include measurements of the radiation dose at the lip of the positioning cone for the usual settings employed by the dentist for bitewing exposures. The results of measurements made in the various years as shown in the Figure 6 which is a log probability plot of patient dose against the cumulative percentage of machines on which the doses were given.

Where machines have not been routinely surveyed, there is always the possibility of operating it at levels which could cause much radiation exposure.

6.3 Filtration

Radiation that cannot reach the film has no diagnostic value. Such radiation has undesirable tissue effects because it is attenuated in tissue somewhere between the skin surface and the film. It becomes important to filter out of the primary X-ray beam those X-ray photons that have little or no chance of reaching the x-ray film because of their absorption by soft tissue.

All machines have an inherent filtration. This is usually insufficient and added filtration is used to bring it to the recommended levels. In dental X-ray machines the added filtration is usually commercially pure aluminium disks.

The filter should be recessed as far as possible behind the diaphragm opening.

EFFECTS OF INCREASED FILTRATION ON PATIENT DOSE AT 45 KVP*

TOTAL FILTRATION (= MM. ALUMINUM)	AIR OUTPUT (R/SEC- OND)	HVL	EX- POSURE TIME (SEC- ONDS)	LOWER MOLAR FILM R (IN AIR)				
				EX- TRAN- CE	26 INCH (GONADS)		36 INCH (OPERATOR)	
					R/FILM	MR/ MA.S.	R/FILM	MR/ MA.S.
1.5	0.7	1.20	0.7	0.49	0.00011	0.010	0.000057	0.0054
2.0	0.5	1.50	0.8	0.40	0.000105	0.0088	0.000050	0.0042
2.5	0.35	1.70	1.0	0.35	0.00010	0.0067	0.000045	0.0030
3.5	0.25	2.05	1.3	0.32	0.000095	0.0049	0.000040	0.0020
4.5	0.18	2.30	1.55	0.28	0.000092	0.0040	0.000038	0.0016
5.5	0.11	2.71	2.0	0.22	0.000090	0.0020	0.000038	0.0013

*CDX-90 II dental x-ray machine; 15 Ma.; Eastman Kodak Ultraspeed film developed for 5 minutes at 68° F.; heavily boned adult male phantom.

EFFECTS OF INCREASED FILTRATION ON PATIENT DOSE AT 65 KVP*

TOTAL FILTRATION (= MM. ALUMINUM)	AIR OUTPUT (R/SEC- OND)	HVL	EX- POSURE TIME (SEC- ONDS)	LOWER MOLAR FILM R (IN AIR)				
				EX- TRAN- CE	26 INCH (GONADS)		36 INCH (OPERATOR)	
					R/FILM	MR/ MA.S.	R/FILM	MR/ MA.S.
1.5	1.1	1.6	0.20	0.28	0.000080	0.0054	0.000036	0.0024
2.0	1.0	2.0	0.22	0.22	0.000076	0.0046	0.000033	0.00198
2.5	0.8	2.35	0.26	0.208	0.000074	0.0038	0.000031	0.00170
3.5	0.57	2.8	0.31	0.176	0.000071	0.0030	0.000027	0.00116
4.5	0.42	3.2	0.39	0.164	0.000070	0.0024	0.000025	0.00086
5.5	0.32	3.5	0.48	0.154	0.000070	0.00194	0.0000244	0.00068

*CDX-90 II dental x-ray machine; 15 Ma.; Eastman Kodak Ultraspeed film developed for 5 minutes at 68° F.; heavily boned adult male phantom.

EFFECTS OF INCREASED FILTRATION ON PATIENT DOSE AT 90 KVP

TOTAL FILTRATION (= MM. ALUMINUM)	AIR OUTPUT (R/SEC- OND)	HVL	EX- POSURE TIME (SEC- ONDS)	LOWER MOLAR FILM R (IN AIR)				
				EX- TRAN- CE	26 INCH (GONADS)		36 INCH (OPERATOR)	
					R/FILM	MR/ MA.S.	R/FILM	MR/ MA.S.
1.5	2.2	2.25	0.092	0.202	0.000074	0.0108	0.000035	0.005
2.0	1.75	2.7	0.104	0.181	0.000072	0.0092	0.0000334	0.0042
2.5	1.45	3.13	0.116	0.168	0.000072	0.0082	0.0000324	0.0038
3.5	1.15	3.8	0.132	0.152	0.000072	0.0072	0.0000310	0.0032
4.5	0.89	4.45	0.144	0.146	0.000072	0.0058	0.0000300	0.0024
5.5	0.77	5.0	0.185	0.142	0.000072	0.0052	0.0000300	0.0022

*CDX-90 II dental x-ray machine; 15 Ma.; Eastman Kodak Ultraspeed film developed for 5 minutes at 68° F.; heavily boned adult male phantom.

Table 16 :- Effects of Inc. Filtration on Patient Dose
at 45 KVP

Table 17 :- Effects at 65 KVP

Table 18 :- Effects at 90 KVP

The area and thickness of the filter affect the amount of scatter radiations reaching the gonads of the patient. The smaller the filter area (for example, the long cone diaphragm has a smaller filter area than does the short cone) the less the scatter radiation will reach the gonads of the patient.

In a comparison involving both a range of kilovoltage and a range of added filtration, Eiter Sidhn and Cross⁴⁰ found that with no filtration, dental radiographic examinations required 16.2 roentgens per film at 60 KVP and 7.8 roentgens per film at 80 KVP. With 2.0 mm aluminium added filtration, examinations required 7.6 roentgens per film at 60 KVP and 2.3 roentgens per film at 80 KVP.

The National Committee on Radiation Protection⁷⁶ in Handbook 76 para 101d it is stated that for dental radiographic "equipment operating up to 70 KVP, the total filtration permanently in the useful beam, shall be equivalent to at least 1.5 mm of aluminium. This equivalent may be assumed to have been met if the half value layer (hvl) is not less than 2.5 mm of aluminium at normal operating voltages." In other words, filtration should be increased with increase of kilovoltage.

In contrast the British Medical Research Council²⁰ observes "The use of techniques employing higher kilovoltages and increased filtration have been advocated in recent years for certain radiographic examinations. It has been possible in this survey to assess the effect of these techniques on the gonad dose with increasing penetration of

the beam the gonad dose at first decreases and then increases. In most measurements the minimum gonad dose occurs with X-rays generated at 70 KVP with a total filtration of about 1 mm of aluminium. A similar variation is shown in the measurements of the skin dose, but the maximum occurs in this case for 70 KVP radiation filtered by a total of about 2 mm of aluminium. These findings do not support the contention that higher kilovoltage and extra filtration necessarily reduce the gonad dose." In another paragraph the Council states :
 "The available evidence would indicate that the gonad dose in dental radiography may be slightly increased by the use of higher penetrating powers."

To reconcile these divergent recommendations it is necessary to compare the methods and criteria of patient dose upon which they are based.

Trout, Kelley and Cathey¹¹⁶ observed that increased filtration reduced patient dose. They intended their findings to apply only to the situation in which the beam must penetrate the entire depth of the part of the body being radiographed before reaching the film. They selected the pelvic examination, in which case the unprotected gonads lie in the direct beam - Fig. 7. In this situation in which an increase in filtration does reduce gonadal dose as well as skin dose and depth dose, conditions are quite different from those of dental radiography where the gonads lie outside the direct beam. Fig 8.

Epps and Associates³⁴ in chest radiography reported no reduction of gonad dose following an increase in filtration although an increase in kilovoltage from 60 to 80 slightly reduced the gonad dose in the male (33 percent). The values at 100 KVP are unchanged from the dose at 80 KVP, whereas at 120 KVP the male gonad dose is increased by 33 percent. In the female the ovary dose is the same at 60 and 80 KVP and is unaffected by an increase in filtration. At 100 KVP the dose is unchanged. When filtration is increased by 1 mm of aluminium; however, with; however, with 2mm added, it is increased by 100 percent and at 120 KVP with 3 mm added aluminium it is increased by 200 percent. The failure of the filtration to reduce gonadal dose in the conditions of Figure 8 results from the fact that the gonads lie outside the direct beam. In this case the gonads receive only scattered radiation and measurements show that the amount of scatter is not reduced by increase in filtration.

Similar findings are reported by Billings and colleagues.²¹

The situation in dental radiography show that the gonads are no longer in the direct beam; and receive scatter at a distance of 26 inches in the adult male. The film is inside the body cavity and not in the position of the exit dose. Film depth is 2.5 mm.

From these conditions Bjaingard and co-workers²⁹ found that the skin dose decreased with increase of half value layer, the dose to the thyroid and submandibular glands were independent of variations in half value layers, the mouth dose increased apparently with half

value layer, the gonadal dose and in all probability, the integral dose increases with half value layer and the further reduction of the other doses e.g., skin dose becomes small at half value layers about 3.0 mm Aluminium. To recommend a half value layer implies a balancing of gonadal dose and integral dose against other doses, primarily the skin dose. A half value layer between 1.5 and 2.5 mm Al can be used as a compromise. This range of half value layers would place the amount of total filtration at 2.75 to 4.25 mm aluminium at 60 KVP and 0.75 mm aluminium at 90 KVP. Bjärngård and Associates found marked increase in gonadal exposure with any increase in filtration.

In contrast to the Handbook 76, the Bjärngård group and the British Medical Research Council recommend decreasing filtration as Kilovoltage is increased.

In view of these results Wainwright¹³⁰ measured patient dose with alterations of filtration and kilovoltage.

In Table 28 at 90 KVP increase in filtration makes it necessary to increase exposure time. Entrance dose decreases slightly with increasing filtration. Gonadal dose and operator dose are affected but little.

Tables 27 and 26 show the effect of increased filtration at 65 and 45 KVP respectively. At these lower kilovoltages, it is also seen that exposure time must be increased as filtration is increased. There are slight reductions in entrance dose as filtration is increased. Scatter to gonads of the patient and to the

operator are effected very little by increase of filtration.

In view of these Wainwright observes¹³⁰ that

1. The recommendation that filtration and kilovoltage be increased to reduce patient dosage is applicable only to situations in which the gonads lie unprotected in the direct beam.
2. When the gonads lie outside the beam as in dental radiograph an increase in filtration or kilovoltage reduces skin dose and depth dose only up to the depth of 1 inch which is the plane of the film. Beyond this there is a reversal in which the patient dose is increased by an increase in filtration or kilovoltage and the gonadal dose is unaffected.
3. Increases in filtration or kilovoltage do not decrease the patient dose in dental radiography when an effort is made to keep the gonad, skin and integral dose as low as possible.

Filtration and Quality

Grandel³² produced intraoral radiographs with a dental X-ray generator operated in 4 modes.

1. 65 KVP with no added filtration
2. 65 KVP with 1.75 mm Al. added Filtration
3. 90 KVP with no added Filtration
4. 90 KVP with 3 mm Al added Filtration

...
Diagnostically best radiographs were obtained with 90 KVP and no added filtration and the worst were with 90 KVP and 3 mm Al. added filtration.

6.4 Collimation

Collimation refers to the control of the beam size and shape of the X-ray beam. The opening in the shield of the head of the X-ray machine through which the beam emerges is usually circular, it could be rectangular.

The beam should cover the area or object being examined and should be larger only to the extent of allowing for small errors in the alignment of the beam, object and film. For intra-oral radiography, the diameter of the circular beam of radiation of the patient's skin need be no greater than $2\frac{3}{4}$ inches. If a rectangular beam is used, its dimension at the skin should be approximately $1\frac{1}{2} \times 2$ inches. Use of rectangular collimation necessitates rotation of the collimator to accommodate for films placed either longitudinally or vertically.

One of the two methods of collimation usually employed in dental radiography

1. Diaphragms (round or rectangular)
2. Metal cylinders, cones and rectangular tubes.

Collimating devices do not materially reduce the amount of radiation received by the exposed tissues, but they do materially reduce the amount of radiation to those tissues that surround the area being examined by preventing unnecessary beam divergence.

It has been stated by the National Council on Radiation Protection (NCRP) that among the most important technical methods

TABLE 19

Doses (millirads) to body sites during occlusal examinations at 60 KVP, FSD 15.5 cm., 0.5 mm. aluminum added filtration

Sites	Upper incisors 8 Ma.S.	Upper cuspid 12 Ma.S.	Floor of the mouth* 8 Ma.S.	Lower 3rd molar 12 Ma.S.
<i>Beam size 6.5 cm. ϕ</i>				
Lens	46	820	8	20
Pituitary fossa	4	2	1	23
Thyroid gland	4	5	20	86
Skin	1,050	1,500	1,010	1,560
<i>Beam size 8.0 cm. ϕ</i>				
Lens	211	754	10	24
Pituitary fossa	3	9	4	19
Thyroid gland	5	9	45	312
Skin	1,040	1,590	1,040	1,590
<i>Beam size 10.0 cm. ϕ</i>				
Lens	557	718	10	431
Pituitary fossa	7	5	14	28
Thyroid gland	9	12	146	536
Skin	943	1,590	1,050	1,590

*Wharton's duct.

TABLE 20

Male gonad dose (millirads) by teeth examined and beam size at 60 KVP, 10 Ma.S., FSD 15.5 cm., 0.5 mm. aluminum added filtration

Teeth examined	Beam size (cm. ϕ)		
	6.5	8.0	10.0
Upper incisors	0.09	0.11	—
Upper cuspid	0.02	—	0.04

All doses measured by Memorial ionization chambers in complete phantom human.

Male gonad doses

for limiting the irradiation of the patient is the use of the smallest practicable X-ray beam and its accurate positioning. For intraoral dental radiography the NCRP stated that the diameter of the beam at the tip of the positioning cone "should not exceed 6 cms and shall not exceed 7.5 cms."

For the usual intraoral film of dimensions $1 \frac{5}{8}$ in x $1 \frac{1}{4}$ in, the diagonal is 5.0 cms. For an X-ray tube with a focus-skin distance of 10 cms the beam diameter necessary at the tip of the positioning cone to cover the film a further 3 cms away is only 3.8 cms and for a machine with a F.S.D. of 14.5 cms it is 4.2 cms.¹²²

Shigetoshi Antoku and colleagues² in a study sponsored by the Atomic Bomb Casualty Commission studied the effect of beam size on the dose received by the patient in routine dental radiography. Table 19. They studied the bone marrow doses to body sites in a phantom according to teeth examined at 60 KVP, 10 Ma.S. F.S.D. 15.5 cms, 0.5 mm Aluminium added filtration and field sizes of 6.5, 8.0 and 10 cm diameter.

There is a significant drop in bone marrow doses when the beam diameter was reduced from 8 cm to 6 cm and a slight increase when the beam diameter was increased from 8 cm to 10 cms. These could be explained on the basis of

1. effect of primary beam collimation.
2. scatter effect of the long cone.

They further investigated a bitewing examination at 60 KVP, F.S.D.15.5, 0.5 mm aluminium added filtration. They observed an increase in dose as the beam size increased. The results seen and the slight difference in pattern of the skin dose between 8 cms and 10 cms beam diameter can be explained as in the previous instance.

O'Shaughnessy and Mitchell⁸³ studied eight combinations of machine variables Table 24 to obtain the least patient exposure and they observed that collimation was the single most important safety factor. He collimated the primary beam so that the diameter of the beam at the plane of the film was 2.75 inches regardless of the film target distance. The diameter of the beam without any added collimation was 7.5 inches with a 10 inch film -target distance and 24 inches when the 18 inch film target distances were used.

Rectangular collimation offered further reductions in beam size.^{58 & 103} Figure 7 Updegrave using rectangular collimation was able to show that the amount of radiation per exposure could be reduced by 58 percent.

Wuehrmann and Manson Hing observed that the area subjected to primary radiation (assuming the best possible collimating effect of a long cone metal tube with a $2\frac{3}{4}$ inch aperture) is approximately 6 sq. inches. Baum and Morgan⁹ observed that since the conventional type film is 1.9 sq. inches, the area being subjected to primary radiation is about 316 percent larger than necessary to produce a

diagnostic image. This computation is based on the plane or surface area of a single film. If one considers the cumulative effect of overlapping fields in a full month radiographic series and the three dimensional effect of radiation (one must think in terms of volume rather than area) the amount of over radiation resulting from disparity between film size and field size is considerable, because reduction of the beam size makes aiming more critical, the systems developed by several involve a film holder that is permanently attached to the X-ray cone or in some sort of physical contact with it; this keeps the film in the centre of the field.¹¹⁷

6.5 Film Speed and Development.

The dental intraoral films currently available vary in speed by a factor of 12. Still faster films are being manufactured.¹³²

The available extraoral films are of limited speed variability and are of two types - screen and noscreen. The non-screen film exposes the patient to a greater amount of radiation.

The use of higher speed films will reduce greatly the exposure of the patient. The use of Ultraspeed films will reduce the absorbed dose of gonadal tissue from complete examination of the mouth to 0.45 mr, the amount received from natural sources of radiation.

High speed films also eliminate errors due to movement,

especially in children.

Richards in his changes of technique to observe reduction in exposure Table ²² shows that -

1. There is 79 percent reduction on time of exposure when you change from Radialized to Ultraspeed film.
2. Using a high energy developer there was a 20 percent reduction in exposure time.

Williamson¹²²'s observations were as follows :-

Old Technique	New Technique	Reduction in Exposure time to	Reduction in dose per Exposure to
1 Slow film	Ultra speed film	1/5	1/5
2 No added filter	1 mm Al.added filter	No change	2/5

6.6 Scatter

Secondary radiation encountered in dental radiography are from the -

1. Scatter from the machine.
2. Scatter from the tissues of the patient irradiated.

The uncertainty of the dose at which genetic tissue is affected has resulted in regular lowering of recommendations pertaining to permissible dose. Since the gonads do not lie within the path of the primary roentgen beam during dental roentgenographic survey, the only exposure of the region must come either from radiation

Table 2 Dosages in Roentgens For 14 Full Mouth Film Techniques

Film.	Slow				Fast		
	Filter added		None		1mm. Al		1mm. Al
	2 $\frac{1}{2}$ in	1 $\frac{3}{8}$ in	2 $\frac{1}{2}$ in	1 $\frac{3}{8}$ in	2 $\frac{1}{2}$ in	1 $\frac{3}{8}$ in	2 $\frac{1}{2}$ in
Aperture position							
1	28	0	14	0	10	0	4.5
2	32	21	14	10	12	7.6	5.1
3	28	9.6	13	4.6	10	3.5	4.4
442	42	118	20	8.4	15	6.4	6.7
5	27	0	13	0	10	0	4.3
6	43	21	21	10	16	7.6	6.9
7	36	14	17	6.9	13	5.3	5.7
8	47	13	22	6.4	17	4.9	7.5
9	27	11	13	5.4	10	4.1	4.4
10	34	14	16	6.9	12	5.3	5.4
11	5.4	0	2.6	0	2.0	0	0.9
12	17	4.8	8.3	2.3	6.3	1.8	2.8
13	118	2.2	8.9	1.1	6.8	0.8	3.0
14	26	0	12	0	9.4	0	4.1

1. Fast films reduce the doses by a factor of nearly 3.

2. Smaller diaphragm reduces the total dose received by a factor of 2 $\frac{1}{2}$.

3. Added filter of 1mm, Al reduces by 2.

A combination of all three methods reduces dose by a 15, the doses with fast films, filter and small aperture being 7% those with slow films, no added filter and normal aperture.

Old Technique	New Technique	Reduction in Exposure time to	Reduction in dose per exposure to
Slow film	Ultra-speed film	1/5	1/5
No added filter	1mm aluminium added filter	no change	2/5
3.5 min. development	5 min development	3/4	3/4
Greater contrast than may normally be required. Poor detail. Overall fogging from scattered radiation appreciable)	(Good diagnostic quality Contrast adequate. Detail good.)	((Total reduction 3//20th)	(Total reduction 3/50th)

Table 22 Effect of film technique on exposure dose

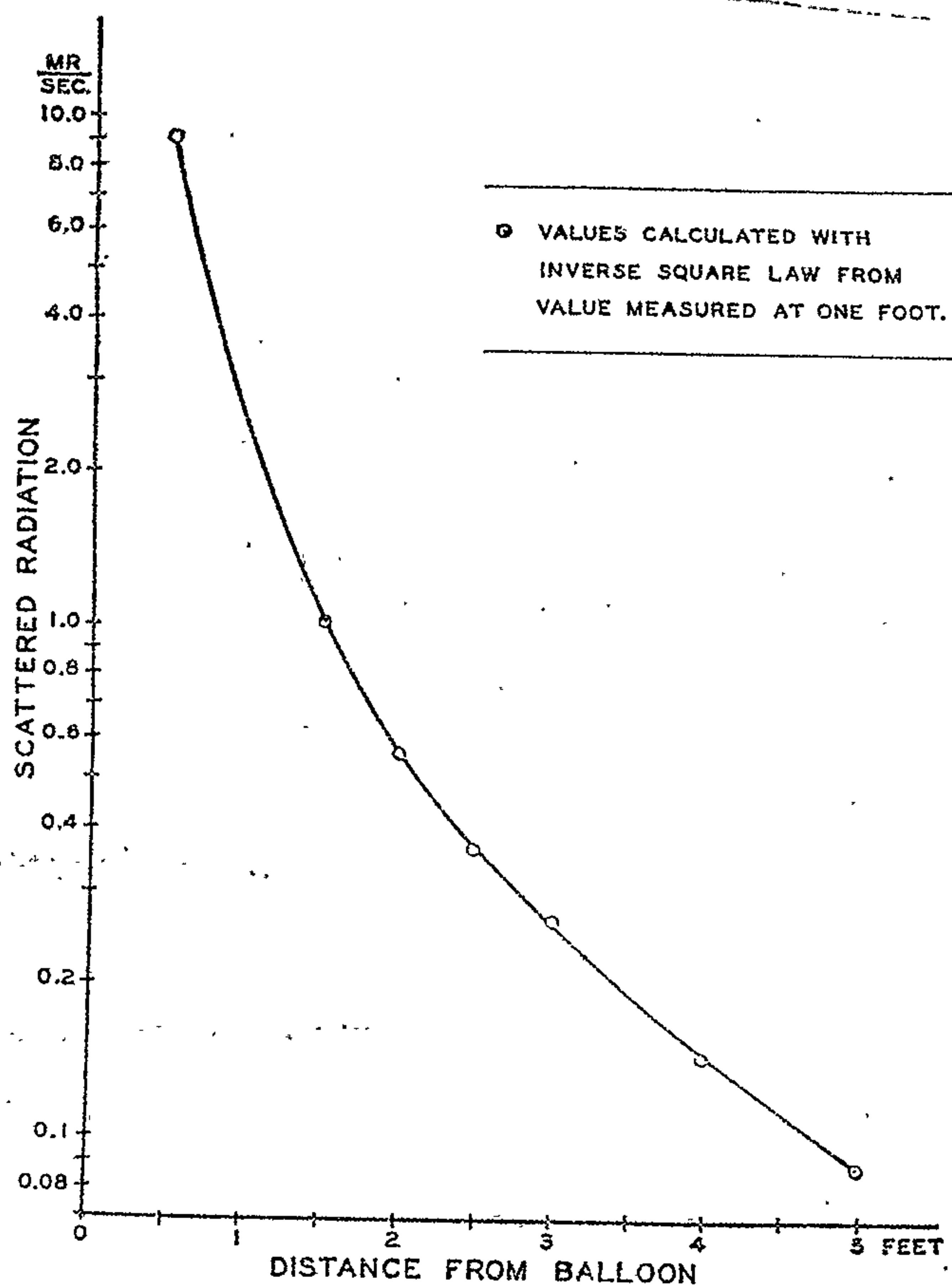


FIG 8 • Measurements made at various distances of amount of scattered radiation given off from water-filled balloon at right angles to direction of central ray. Technical factors: 90 kv.p., 10 ma., total filtration equivalent to 2.25 mm. of aluminum

scattered from the head of the patient through his body or through the air, or from radiation leaking from the head of the X-ray machine.

The following table reports the scale of scatter exposure at 1 metre for X-ray machines with varying cone types -

X-ray machine	Type of Cone	Rate of scatter exposure at 1 meter	
A	Long open ended cone shielded	5	R
A	Short pointed	70	R
B	Long open shielded	7	R
B	Short pointed	95	R
C	Long open unshielded	52	R
C	Short pointed	200	R
D	7 in open unshielded	58	R
D	7 in open shielded	40	R

These results show that the shorter cone if it is open ended and shielded gives the least amount of scatter and next the long open ended shielded cone.

The importance of scatter led Richards¹⁰⁰ to investigate the characteristics of scatter radiation.

1. Secondary radiation scatters in all directions from its point of origin.

2. Next he investigated whether secondary radiation follows the inverse square law and found it applies Fig. He applied the inverse square law to the amount of scattered radiation measured at 12 inches in order to calculate the theoretical amount that should be present.

The small difference between the calculated and measured values

indicate that secondary radiation closely follows the inverse square law. Fig. 8

3. He determined the relative amounts of scattered radiation produced as a function of the voltage employed. The results appearing in the figure 9 indicate that the amount of scattered radiation increases with voltage and almost two and a half times as much scattered radiation is produced at 90 KVP as at 65 KVP.

4. From a wax phantom experiment he calculated the relative amounts of scattered radiation as a function of filtration. The results indicated that the amount of scattered radiation decreased with increasing filtration (65 KVP and 10 Mas. with short cone touching cheek). Figure 11 .

5. Figure 10 shows the effect of Collimation. The diameter of the beam at the end of the short cone was reduced from 3.5 inches to 2.7 inches and the scattered radiation was reduced by almost 30 percent.

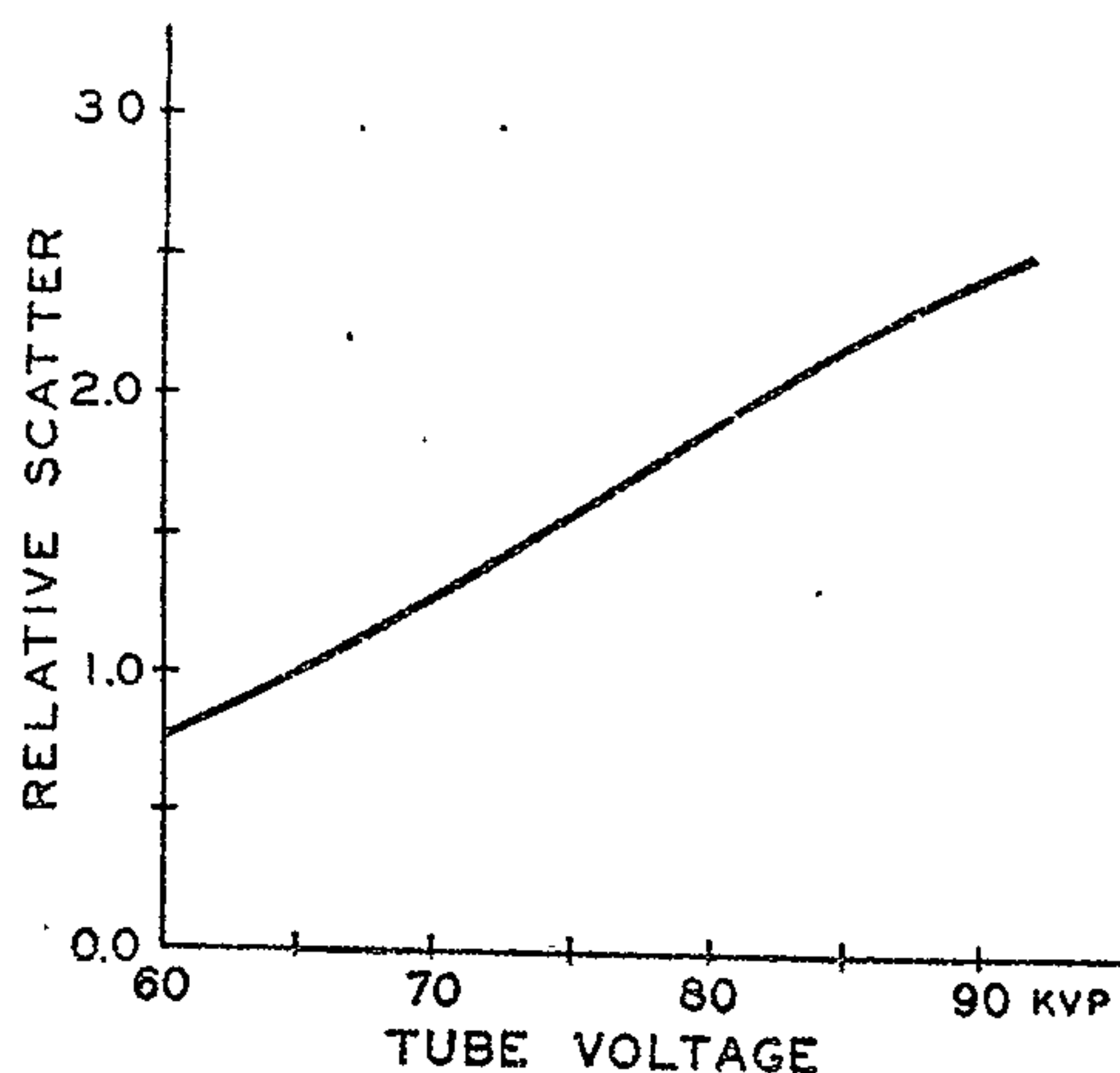


Fig. 9 Relative amount of radiation scattered from water-filled balloon as function of tube voltage. Technical factors: 10 ma., total filtration equivalent to 2.25 mm. of aluminum

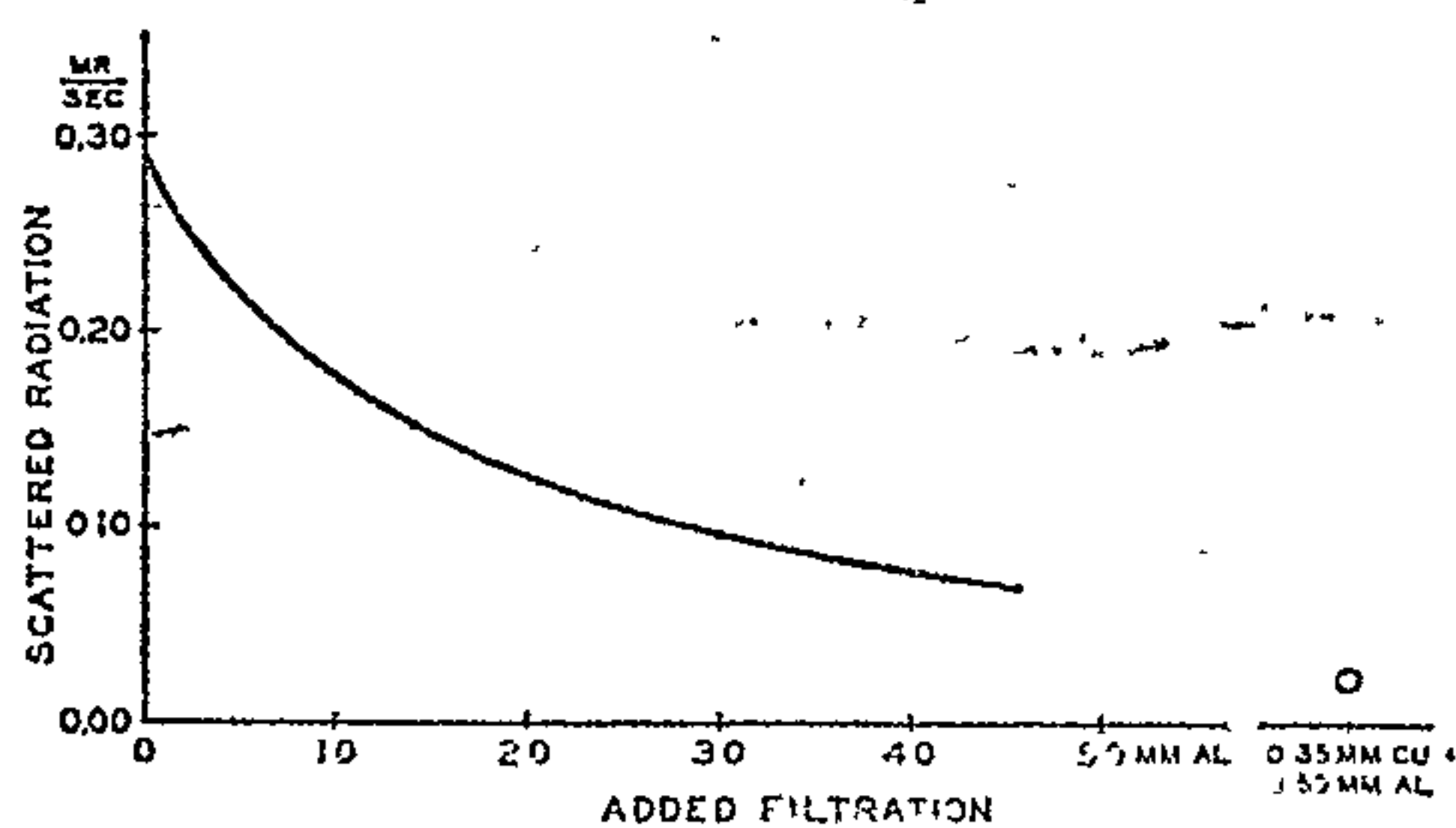


Fig. 11 Amount of radiation scattered from human skull (which had been filled and coated with wax) as function of external or added filtration. Technical factors: 65 kv.p., 10 ma., diameter of beam at 7 in. from target—3.5 in., inherent filtration equivalent to 0.5 mm. of aluminum

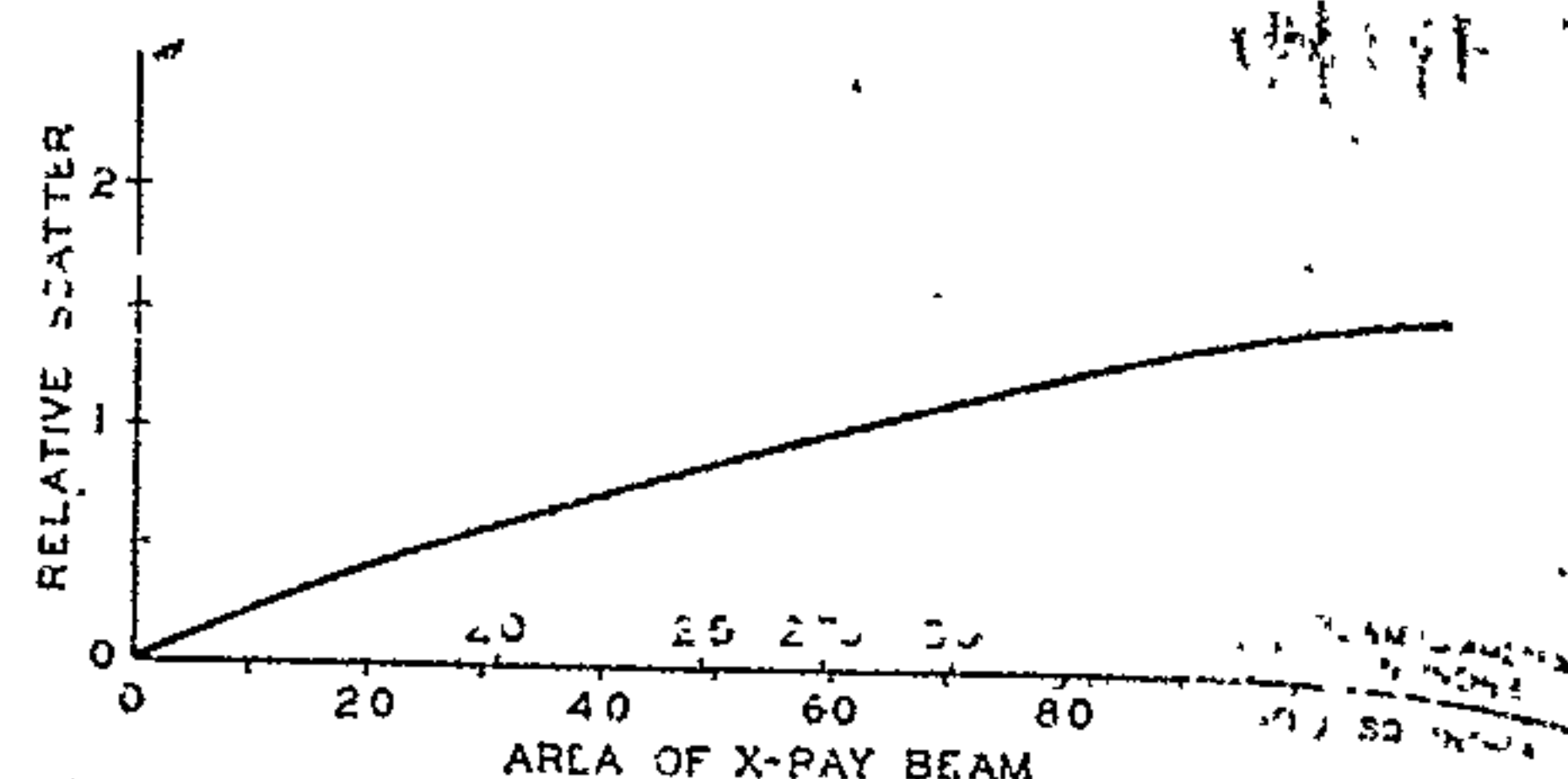


Fig. 10 Relative amount of radiation scattered from human skull (which had been filled and coated with wax) as function of area of roentgen ray beam. Technical factors: 65 kv.p., 10 ma., inherent filtration equivalent to 0.5 mm. of aluminum

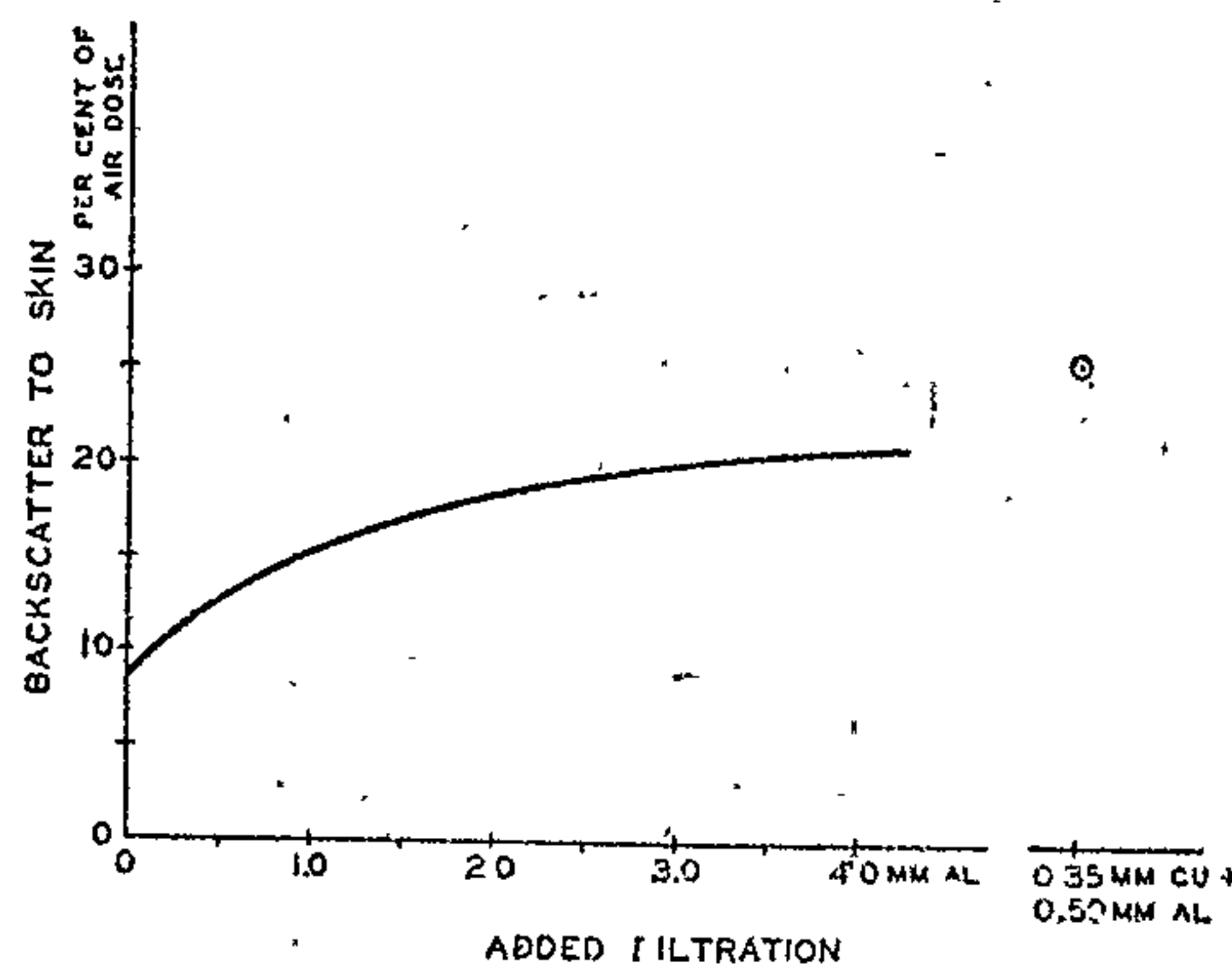


Fig. 12 Radiation scattered back to skin from underlying tissue as function of added or external filtration. Technical factors: 65 kv.p., 10 ma., target-skin distance—7.25 in., diameter of beam at distance of 7.0 in. from target—3.5 in., inherent filtration equivalent to 0.5 mm. of aluminum

6.7 Effect of factors in combination

There are several studies where they have used these factors in combinations to arrive at the most satisfactory combination as regards patient exposure and diagnostic quality of the radiograph. Two of the studies that have contributed most to the knowledge in this area are one by Frey and Wuchrmann¹³⁹ and the other by O'Shaughnessy and Mitchell.⁸³

Frey and Wuchrmann¹³⁹ studied the absorbed doses of x-radiation to a Rando phantom head by seven intraoral radiographic techniques measured during the production of acceptable single molar bitewing radiographs. Techniques included three kilovoltages (50, 65 and 90 KVP), three sources to skin distances (4.5, 8.5 and 16.5 inches) and ten types of positions indicating devices (lead lined cylinders and pointed plastic cones). One hundred and fourteen thermoluminescent dosimeters were placed in the head and positioned to measure intra-beam and extrabeam doses. Skin entrances were higher for low KVP and plastic cone techniques. Doses recorded at skin exit surfaces were low and indicated that little radiation escaped from the phantom during exposure. Single bitewing film surface doses which produced comparable film densities ranged from 70.35 m rads to 79.95 in rads for all except the 50 KVP technique, which required a dose of 95.75 m rads. The 65 KVP, 16.5 inch source to skin distance and the open end, lead lined cylinder technique. Techniques utilizing pointed plastic cones delivered the greatest total doses, with the 50 KVP, 4.5 inch source to skin distance, and pointed cone technique ranking poorest.

In the study by O'Shaughnessy and Mitchell⁸³ the three X-ray machine variables target film distance, filtration and collimation were studied to determine which of the eight combinations of these was the safest to use during routine intraoral roentgenography. The eight combinations were used at 70 KVP, 80 KVP and 90 KVP levels, making 24 combinations in all. Ionization chambers were placed in seven regions in a cadaver; the pituitary body, thyroid gland, porta hepatis, hilus of the spleen, adrenal gland, testes and femur, after which intraoral roentgenographic examinations with each of the 24 combinations were performed. The dose level to each region with each combination was determined by reading the amount of ionization within the dosimeter. No single combination was the safest for all seven sites, although the long cone, added filtration and collimated beam combination was best for five of the seven region and extremely low for the other two. *Tables 24, 25*

Radiation doses to body regions with 70 k.v.p. Levee nr/ratt film site

Table 24

	Pituitary: Body	Thyroid gland	Liver	Spleen	Adrenal gland	Testes
6--						
Long cone no added filtration no collimation	32.0	40.0	1.2		0.2	0.4
Long cone added filtration no collimation	55.0	112.0	1.0	0.5	nr	nr
Long cone no added filtration collimation	4.2	4.7	0.8	0.3	nr	nr
Long cone added filtration collimation	3.8	4.2	nr	nr	nr	nr
Short cone no added filtration no collimation	32.0	33.8	0.5	0.2	0.5	0.1
Short cone added filtration no collimation	32.5	35.0	0.5	0.2	0.5	0.1
Short cone no added filtration collimation	2.5	2.9	0.6	0.3	0.4	0.1
Short cone added filtration collimation	2.1	2.8	0.6	0.3	nr	0.1

Table 24: Radiation dose to body regions with 80 kvp level
mr/r at film site.

	Pituitary	Thyroid	Liver	Spleen	Adrenal	Testes
Long cone no added filtration no collimation.	53.3	52.5	1.3	0.3	0.5	0.3
Long cone added filtration no collimation	90.4	175.0	0.8	nr	nr	nr
Long cone no added filtration collimation added	4.16	4.8	0.8	0.3	0.3	nr
Long cone added filtration collimation added	3.0	3.0	nr	nr	nr	nr
Short cone no added filtration no collimation.	41.3	46.5	0.6	0.3	0.5	0.1
Short cone added filtration no collimation	36.6	36.6	0.5	0.2	0.5	0.1
Short cone no added filtration collimation added	2.5	2.7	0.8	0.4	0.6	0.2
Short cone added added filtration added collimation	2.1	2.8	0.6	0.3	0.3	nr

* nr not recorded

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Table 25 Radiation dose to body regions with 90 k.v.p. level mr/r

| | Pituitary | thyroid | Liver | spleen | adrenal | testes |
|--|-----------|---------|-------|--------|---------|--------|
| Long cone no added filtration no collimation | 72.7 | 67.9 | 1.5 | 0.5 | 0.8 | 0.5 |
| Long cone added filtration no collimation | 105.9 | 208.5 | 0.9 | 0.3 | nr | nr |
| Long cone no added filtration collimation | 3.9 | 4.0 | 0.9 | 0.4 | 0.3 | nr |
| Long cone added filtration collimation | 2.2 | 3.9 | nr | nr | nr | nr |
| Short cone no added filtration no collimation | 45.4 | 46.2 | 0.8 | 0.5 | 0.7 | 0.3 |
| Short cone filtration added no collimation | 40.6 | 42.8 | 0.7 | 0.3 | 0.6 | 0.2 |
| Short cone no added filtration collimation added | 2.2 | 2.2 | 0.7 | 0.3 | 0.5 | 0.2 |
| Short cone added filtration collimation | 2.2 | 2.4 | 0.6 | 0.3 | 0.4 | 0.1 |

Chapter 7 Chemical Protection from Radiation Damage^{14,17,31}

Various substances have been shown to alter lethal effects of ~~conying~~ radiation when they are present in the cell before or during irradiation. These fall into two groups¹⁴ - 1. sensitizers and 2. protectors.

Sensitizers - As a radiation sensitizer, oxygen is certainly the most important example, and probably acts at two levels. First in the aqueous medium of the cell it leads to the formation of O_2^- and HO_2 , as well as H_2O_2 . Secondly, it may attack organic molecules directly leading to the formation of peroxyradicals, which prevent normal repair reactions. This sensitizing effect has been utilized by administering high pressure oxygen to patients receiving X-radiation for neoplastic disease in an attempt to differentially increase radio sensitivity of the tumor, relative to surrounding normal tissue. Other sensitizers described are halogenerated pyrimidine derivatives (Badr) and (1 ridr). These compounds exert their radiosensitizing effects by being incorporated into the replicated DNA strands and thereby imparting structural weakness to the DNA chains at those points of incorporation. Persons receiving these drugs for therapeutic purposes have a known contraindication for X-irradiation and should receive the latter only under highly indicative and carefully controlled conditions.

Protectors The approach to chemical protection is to look for agents which when administered would lessen or prevent the effects of acute whole body radiation.

The review by Bacq¹⁷ of chemical radiation protection as reported by Bixter¹⁴ :-

Protectives fall into two general groups. The first group includes diverse substances such as histamine, cyanides, catecholamines, p - aminopropophenine (PAPP), and some anaesthetic agents that are protective primarily by producing systemic hypoxia. The second group consists of thiols and disulfides. The working hypothesis is based upon the idea that radiation produces toxic agents in the cell and these agents will oxidise the sulphhydryl (-S-S-) groups of the protein chains of enzymes. When this occurs, enzymatic activity is lost and cell death follows. Hence any agent that protects these sulfhydryl groups will lessen and prevent the damage subsequent to cell radiation. The following compounds have been shown to be effective in radiation protection: cystine, glutathione, methionine, theourea, mercaptosuccinate, thio-sulphate, and S, beta - amino-ethylisothiuronium bromide (AET).

Crough and Overman³¹ have described an experiment by Patterson⁸⁷ on the effect of AET. Pallis on using *Macaca mulatta* monkeys found that 100 percent of the animals die as a result of 600 r of whole body X-radiation administered in a single dose. In this experiment one animal was injected intraperitoneally on successive days with the following doses of AET : 100, 150 and 200 mg/kg of body weight. Three days after the 200 mg injection, the animal was given 250 mg/kg and was immediately irradiated with 650 r of whole body X-radiation. The animal was surviving at 200 days post irradiation and was apparently normal. A second monkey was injected with slightly varying doses and times of injection. This animal was observed also apparently

normal.

Peripheral blood studies of the two animals were indicative of the protective ability of the drug.

Since then Crough and Overman³¹ submitted 4 monkeys to 150 mg AET per kilogram of body weight in a single dose prior to administration of 650 r of whole body X-radiation. Observed after 30 days they appeared normal and peripheral blood studies are in keeping with Paterson's findings.

Chemical protection from radiation would have great meaning to astronauts atomic physicists and individuals working with nuclear reactors. There is even potential meaning of such protective agents for public health medicine in the event of a nuclear war. Chemical protection is still an experimental tool and more studies must be forthcoming before the significance of this concept as a public health measure.

NEWER TECHNIQUES.

1. PANOGRAPH, PANOROMIX
2. ORTHOPANTOMOGRAPH, PANOREX
3. XERORADIOGRAPHY.

To study the deleterious effects of the different radiographic examinations, dose measurements are used to compare with the conventional intra oral technique.

Conventional and panaromic complete mouth X-ray examinations differ in so many respects that a comparison of the amount of radiation administered to the patient cannot be made with the use of exposure measurements in roentgens. The integral absorbed dose, being the total amount of energy absorbed by the patient and expressed in gram rads or ergs, is more suitable for this purpose.

Van Akens and VanLindens¹²⁰ experiments have given the results shown in Table 27 for oral examinations.

TABLE 26

| | Conventional
Technique | Panoramic examination | |
|--|--|---|---|
| | | Panoramix | Orthopantomograph |
| X-ray tube | Extraoral | Intraoral | Extraoral |
| Film | Intraoral | Extraoral | Extraoral |
| Advantages | Good detail | Relatively good | One exposure; complete mandible, including temporomandibular joint, is shown. |
| Disadvantages | Restricted to teeth & surrounding structures; sixteen exposures. | Poor projection of upper molar area; often overlapping of teeth; two exposures. | Less detail; tomogram of a layer of limited thickness. |
| Integral absorbed dose (rounded off to 2 digits) | 10^5 ergs; 1000 gram rads. | 1.9×10^3 ergs; 19 gram rads. | 1.1×10^4 ergs; 110 gram rads. |

Table 27 Mean values of the gonadal dose under variable conditions when making fifteen film complete mouth examinations.

| KVP | Half-value
layer mm
aluminium | N* | Occlusal plane
gonadal distance
cm | Gonadal dose
mr |
|-----|-------------------------------------|-----|--|--------------------|
| 60 | 1.4 | 114 | 64.3+/-1.3 | 0.712+/-0.052 |
| 55 | 1.9 | 110 | 63.2+/-1.4 | 0.862+/-0.068 |
| 65 | 2.3 | 110 | 64.1+/-1.9 | 1.213+/-0.106 |

Table 28

Mean values of the gonadal dose resulting from surveys using the Panorex method under variable conditions.

| Protection | KVP | Half value layer
mm.Al. | Ma. | N | Occlusal plane gonadal
distance, cm. | Gonadal dose
mr |
|-------------|-----|----------------------------|-----|----|---|--------------------|
| Without Pb. | 70 | 1.8 | 6 | 18 | 66.8+/- 1.0 | 0.450+/- 0.030 |
| | 70 | 11.8 | 5 | 13 | 64.1+/- 1.0 | 0.483+/- 0.029 |
| With Pb. | 70 | 1.8 | 6 | 12 | 68.3+/- 1.5 | 0.105+/- 0.008 |
| | 70 | 1.8 | 5 | 14 | 67.1+/- 1.4 | 0.089+/- 0.005 |
| | 65 | 1.65 | 5 | 11 | 60.6+/- 1.2 | 0.098+/- 0.005 |

Without Pb. indicates lack of additional protective shield over tube housing

With Pb. indicates use of such a shield.

N = number of surveys.

Table 29

Mean values of the gonadal dose resulting from surveys using the Orthopantomograph method.

| Half
KVP | Half value layer
mm.AL. | Ma. | N. | Occlusal plane gonadal
distance cm. | Gonadal dose mr |
|-------------|----------------------------|-----|-----|--|-----------------|
| 80 | 2.85 | 15 | 110 | 68.7+/- 1.4 | 0.116+/- 0.008 |
| 76 | 2.7 | 15m | 8 | 62.1+/- 1.9 | 0.103+/- 0.008 |

N= number of surveys.

Table 30

Mean values of the gonadal dose resulting from surveys using Panoramic method under different conditions

| Protection | KVP | N | Occlusal plane gonad distance
cm | Gonadal dose mr |
|-------------|-----|----|-------------------------------------|-----------------|
| Without Pb. | | | | |
| Upper jaw | 55 | 17 | 63.7+/- 1.5 | 0.102+/-0.010 |
| Lower jaw | 50 | 18 | 63.5+/-1.3 | 0.1152+/-0.004 |
| With Pb. | | | | |
| Upper jaw | 55 | 15 | 70.0+/- 1.6 | 0.0076+/-0.0008 |
| Lower jaw | 50 | 16 | 68.1+/- 1.7 | 0.033+/-) .003 |

Without Pb indicates no shield to protect portions of the oral cavity which are needlessly exposed. With Pb indicates the presence of such a shield. N=number of surveys.

Genetic effects of radiation being the most important, Jung⁵³ investigated the genetic dose by the new methods and compared the integral dose delivered to the gonads, with the dose delivered by the conventional ultra oral techniques. The Table 28, 29 and Fig. 30 show the results.

These findings constitute an argument in favour of the new techniques and emphasize the need to consider them when selecting a technique for a complete mouth examination.

Xero Radiography⁸⁴

It is a relatively new method used in diagnostic radiology. It is an electrostatic imaging system.

Xeroradiography may have a great potential for examining the anatomically complex maxillofacial region, which is difficult to demonstrate with conventional Xeroradiographs. Its range of applicability is wide, since structures of wide variation in radiodensity record equally well. While Xeroradiography is an extremely interesting process that produces images not possible with standard techniques, consideration must be given to the amount of radiation to which the patient is exposed. The individual receives as much as 6 to 8 times greater radiation for a lateral jaw Xerogram even with high Kv technique and more than that when other techniques are used. It is therefore appropriate to use discretion in applying Xeroradiography to maxillofacial diagnostic procedures and to reserve it for cases in which it is of greater value than standard radiology.

8. Future Hazards in Dental Radiography.

The field of dental radiography is fast expanding. Due to the advances in knowledge in the field of nuclear energy and electronics there are new and exciting discoveries which are influencing dental radiography.

U.V. Radiation.

Non ionizing radiation in the ultraviolet spectrum induces cancers of the skin of experimental animals with quantitative predicatability. The long wavelength limit for the carcinogenic action lying at about $0.32/\mu$ Sunlight having its shortest wavelength limit at about $0.29/\mu$ contains a small fraction of these carcinogenic wavelengths, and the evidence converges to indicate that this is a principle cause of cancer of the skin in man. The carcinogenic wavelengths are the same as those that cause sunburn.

- Blum⁴ induced cancer of the skin in mice by exposing them to repeated doses of ultraviolet light and made these observations. -
1. There is no evidence of a threshold dose below which cancer is not induced.
 2. There is a slight degree of recovery from the carcinogenic process and so it is possible that a threshold exists at some very low level and it is completely infeasible to determine what the threshold is if it exists.
 3. Carcinogenesis by ultraviolet light is a cumulative process and for all practical purposes may be regarded as essentially irreversible and with no threshold.

Recently composite material polymerized by U.V. radiation have been used as a filling material in dentistry.¹²¹

8.2 Cinefluorography.⁵

Cinefluorography (cineradiography) may be defined as the cinematographic recording of a fluoroscopic image formed on a conventional fluoroscopic screen or on the output screen of an image intensifier by means of a cinematographic camera^a optically coupled to the screen.

The medical radiologist uses cinefluorography widely in routine practice. H.K.Cooper and his staff of the Lancaster (Pa) Cleft Palate Clinic have employed this modality since 1954 for assessment of speech physiology in cleft palate patients. Also in that year Berry and Hofmann undertook research studies of the functioning of the temporomandibular joint, leading to the development of the Cineradiographic Circle Unit.

The cineradiographic circle unit permits simultaneous recording of three parameters of mandibular movements for better understanding of the working role of the temporomandibular joint. This system allows the patient to sit in a natural, comfortable position during the entire data recording session. This eliminates operator induced error which prevents retakes and the quality helps in diagnosis.

8.3 Thermography

Gersham-Cohen et al^{49 16} have described thermography as the art of obtaining an image reproduction of the impared radiation

spontaneously emitted by an object. All objects give off impaired radiation as a function of their temperature. In order that a balance may be obtained in nature, ~~diverse~~ ^{diverse} infra-red radiation is being continuously emitted, absorbed and remitted by everything in an environment. The human body normally gives off 3 to 20 microns of infra-red radiation. Scanners such as that described by Barnes can record heat images (thermograms) on photographic film or electrochemical paper. Most of the early work has centered on thermographic breast examination for the bright areas recorded by malignant lesions. Modifications in equipment design could possibly make intraoral thermography a useful tool in dental radiography.

8.4 Ultrasonic Echograms.

Ultrasonic echo sounding has been used for locating intracranial tumors³⁵, mitral valve studies, kidney stones and other intra abdominal studies and in 1965 was effectively by dental residents at Philadelphia General Hospital for locating non radio opaque foreign bodies embedded in facial tissues following severe traumatic accidents. A transducer momentarily excited by a high frequency current transmits sound vibrations to tissue fluids; when these collide with the surface of a different medium, they travel back to a piezo-electrical crystal which has the property of generating an electrical signal which may be recorded or displayed on oscilloscopes, stripcharts or photographic film.

Recently they have investigated the use of ultra sonic

techniques to aid in the technique of root canals therapy.⁸⁰

99, 78, 77, 59

9. Codes for Radiation Control

Although man made radiation has been present since the beginning of the twentieth century, there was little effort to regulate it as a health hazard. The main reason for this was that it was then almost exclusively in the hands of the medical profession or scientific investigators. It has long been conceded that both these groups should be given the greatest possible freedom in order not to impede medical needs and scientific progress. It was not until radiation appeared as a significant health hazard in industry in the 1940's that any serious effort was made to regulate it.(1)

The National Council in Radiation Protection (N.C.R.P.) developed a set of standards. All users were urged to follow the established standards but it was on an entirely voluntary basis. In recent years many states and cities in the United States have enacted laws and promulgated regulations based upon the recommendations of the N.C.R.P.^{78,77,59}. Such laws and regulations are being constantly amended in order to follow recently developed standards.(2) In Australia there is a Radioactive Substances Legislation which is applicable in the different Territories of the Commonwealth and in the States. The Radiation Branch, Division of Occupational Health and Pollution Control of the Health Commission of New South Wales has issued a series of Safety Codes⁹⁹ setting out requirements

for safe use of radioisotopes and X-ray equipment. These codes are not statutory, but define the principle safety standards used by the Radiation Branch as a basis for assessing the radiological health aspects of applications for licence under the New South Wales Radioactive Substances Act.(4)

In the State of New South Wales for the operation of X-ray apparatus you require the following licenses :

1. License to buy and possess X-ray equipment.
2. Operate X-ray equipment :- This requires qualified personnel except for dental X-ray machines where the responsibility is taken by the dentist.

The Code of Practice as mainly applicable to Dentistry.

A. Personnel

A1. 1. Responsibility.

Responsibility for the observance of this Code shall rest with the persons or organizations having administrative control over medical X-ray installations, and with relevant licenses under the Radioactive Substances Act.

Licenses shall be specifically responsible for -

- (a) establishing and maintaining operational procedures so that radiation exposure of each worker is kept as far below the maximum permissible exposure as is practicable :
- (b) instructing personnel in safe working practice and in the nature of injuries resulting from over exposure to X-rays;
- (c) assuring that personnel monitoring devices (including film

badges) are used where indicated and the records are kept of the results of each monitoring :

(d) investigating any case of excessive or abnormal exposure to determine the cause and for taking steps to prevent its recurrence;

(e) observance of all other relevant requirements of the Radio-active Substances Act and Regulations.

A2 Qualifications of Operators

X-ray equipment shall be operated only by persons competent in its use.

As Dental X-ray generators come within the category with low current ratings less than 50 milliamperes. They may be operated under medical supervision, by persons who have been instructed by a competent authority in basic radiation safety principles and are competent to use the apparatus in accordance with accepted radiographic techniques.

B1. Safety Rules for Radiography

Medical radiography is responsible for the greatest part, by far of the genetic dose to the general population from man made radiation and should only be used with discretion. The following sections have been designed with the object of achieving minimum radiation exposure of patients with X-ray staff compatible with adequate clinical diagnosis.

B21 Equipment

+ Tube Housing.

The radiation leaking through the tube housing in any direction outside the useful beam shall not exceed 100 mR/hr at a distance of 1 metre from the target when the tube is operating at its maximum current for maximum rated voltage.

B22 Filtration

(a) For voltages greater than 70 KVP use total filtration permanently in the useful beam shall be not less than 2.5 mm of aluminium equivalent.

(b) For voltages up to 70 KVP, the total filtration permanently in the useful beam shall not be less than 1.5 mm of aluminium equivalent.

B2.3 Cones and Diaphragms

The use of diaphragm or metal collimators to restrict the useful beam to a diameter of $2\frac{3}{4}$ inches when striking the face.

B2.4 Protective Screens etc.

The operator's station at the control should be either -

- (a) in a separate room
- (b) in a protected booth or
- (c) behind a shield which will interrupt the useful beam and any radiation which has been scattered only once

B.2.4 (d)

The operator should stand at least six feet from the patient and from the useful beam of primary radiation. When this is not possible, he should stand behind a protective barrier to radiation : Never stand unprotected in the path of the useful X-ray beam that passes from your X-ray aperture. The beam can be avoided by standing behind the patient if possible, and between 90° and 135° to the X-ray beam during X-ray exposure.

B2.5 Non shockproof equipment

All X-ray equipment should be shockproof.

B2.6 Technique Charts

Where the machine may be used by persons other than a qualified medical radiographer, a chart, indicating the exposure factors required for the various examinations for which the X-ray unit may be used, shall be readily available adjacent to the controls.

B3. Procedure

31 Minimum Exposure of Patient

The dose to the patient should be kept to the minimum consistent with clinical requirements.

B3.2 Limitation of the Useful Beam

For every radiograph, the dimensions of the useful beam shall be restricted to the minimum compatible, which should be no larger than clinically necessary.

B3.3 Holding Patients, Film, Generating X-ray Tech.

X-ray staff should not hold children or or support infirm or injured patients during radiographic examinations. Where necessary such patients should be supported or held by persons, preferably elderly, not occupationally exposed to radiation.

B3.4 Minimum Exposure to Ancillary X-ray Staff

Procedure and room layout shall be such that radiation exposure of clerical staff, attendants, receptionists and other ancillary X-ray workers will be kept to a minimum.

B 3.5 Film Speed

The fastest available film with adequate clinical diagnosis should be used.

B3.6 Processing Film

X-ray films should be processed using the development time and ~~and~~ conditions recommended by the manufacturer. Arrangements should be made for regular replacement or replenishment of solutions.

3.7 Repeated Exposures

The utmost care should be taken to obviate the necessity for repeat exposures.

3.8 The Dental X-ray Unit shall incorporate a clearly discernable audible signal to indicate that the radiograph exposure has terminated at the end of the preset exposure time.

D. PERSONNEL MONITORING

D1 General

Recommendations as to the maximum permissible dose of radiation for all categories of the population are periodically announced by the International Commission on Radiological Protection, and are incorporated in the legislation of New South Wales in the Radioactive Substances Act.

Individual radiation doses received by X-ray workers in the course of duty may conveniently be measured and recorded by use of personnel monitors and compared with the maximum permissible dose. Such measures are a guide to the effectiveness of the foregoing provisions and procedures in reducing radiation dosage. The reliability of such measurements depends on close adherence of the worker to the instructions accompanying this particular monitoring device.

D2 Use of Film Badges

All personnel for whom there is a likelihood of significant exposure to radiation, shall wear film badge monitors supplied by and assessed by the Radiation Brand Division of Occupational Health and Pollution Control, Health Commission of New South Wales, or by other approved organizations.

D3. Maximum Permissible Dose

The current (1964) maximum permissible doses as incorporated in the regulations under the Radioactive Substances Act are as follows :

- a. In addition to the radiation worker -
1. Whose whole body or the major portion thereof has been or is likely to be exposed, in the course of his occupation, to ionizing radiation from external and/or internal sources, means a dose not exceeding 3 rems in any period of thirteen consecutive weeks or 5 rems in any year, to the gonads and blood forming organs; or -
 - (ii) whose whole body or the major portion thereof has been or is likely to be exposed in the course of his occupation, to ionizing radiation from external sources, means a dose not exceeding 8 rems in any period of thirteen consecutive weeks to the skin and the thyroid gland; or -
 - (iii) Whose hands and forearms only, head and neck only or feet and ankles only have been or are likely to be exposed, in the course of his occupation, to ionizing radiation from external sources, means a dose not exceeding 20 rems in any period of thirteen consecutive weeks to the skin, the deeper tissues of hands, forearms, head, neck, feet or ankles; or -
 - (iv) who is under the age of eighteen years and who in the course of his occupation is exposed internally or externally to radiation from any irradiating apparatus and/or radioactive substance, means a dose not exceeding 3 rems per year to the skin and the thyroid gland, and 1.5 rems per year to the gonads and blood forming organs.
- b. In relation to any other person means a dose not exceeding 0.5 rems per year to the gonads and blood forming organs.

c. For the purpose of calculating the maximum permissible dose in relation to any other person referred to in paragraphs (a),(b)(c), of this definition, natural background radiation to which such a person is subjected and any radiation to which such a person is subjected in the course of any medical procedure, shall not be taken into consideration.

D4. Occupational exposure of Pregnant Women

Women of reproductive age should be occupationally employed only under conditions where the exposure of the abdomen is limited to 1.3 rems in a 13 week period, corresponding to 5 rems per year delivered at an even date.

Conclusions.

In the previous pages literature related to radiological health has been reviewed in an attempt to provide a knowledge of the proper use of radiological techniques. The place of radiology in the diagnosis of dental disease is well established hence it is of great concern to see that the patient irradiated, the dentist and other personnel who form the dental team in the surgery are protected from any hazards associated with the use of radiological techniques.

Radiation has physical, biological and chemical effects, but the effects we are most interested in here are the biological. These are the ones which are described and evaluated. Radiation in large doses has been shown to kill, to produce cancer, to cause blood disorders, and to induce cataracts in the eye. They can cause skin burns, abnormal pregnancies and malformed offspring. On the other hand it is used by physicians to treat cancer and skin disorders.

Even in relatively small doses, there is statistical evidence that radiation can cause certain damage to genetic material. It is suspected of affecting man's life span and increasing his likelihood of suffering from certain illnesses like leukemia.

The current maximum permissible dose has been set at 550mr during the reproductive years 10 to 40 years of age. In the review of literature by the combination of techniques it has been shown that the dentist need not allow his dental patient to receive gonadal radiation doses anywhere near the maximum dose that is permissible.

However Wainwright's ¹¹³⁰ figures of 0.05 mr per film would ^{permit} the dentist to take 10,000 dental films during the 30 year period or at an average of more than three hundred per year.

Richards ¹¹⁰⁰ indicates that 46 complete roentgenographic examinations of an adult man would expose his reproductive cells to about 1100 mr. He compares this with 30 years exposure to the testing of atom and hydrogen bombs and that from natural sources of radiation like cosmic rays from the heavens, and the radioactive minerals in their bodies. His observations are interesting in that the testing of atom and hydrogen bombs would deliver about 100 mr and from natural sources approximately 4300 mr would be delivered during the same period.

These figures should not encourage complacency because many dentists ^{use} faulty techniques and faulty machines and hence expose their patients to unnecessarily high doses.

This was observed by Menozers⁷¹ in the Connecticut area where dentists were delivering 8 to 88 mr to the gonads in routine surveys and their attitude towards potential radiation hazards^s was poor and unconcerned.

The important question that may never be answered is this: Since man has always been exposed to substantial amounts of radiation from nature to how much additional radiation radiation can he be exposed without any unreasonable risk to himself or his progeny? As in the case of many occupations¹ or environmental hazards this will probably have to be answered in terms of the benefits which accompany the risks.

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